Abstract Journal in Earthquake Engineering

Volume 9: 1979 Literature
December 1980
Earthquake Engineering Research Center
University of California, Berkeley

INFORMATION RESOURCES
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Earthquake Engineering Research Center
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Contents

Preface

The *Abstract Journal in Earthquake Engineering* is a comprehensive annual collection of abstracts and citations of current literature pertinent to the field of earthquake hazard mitigation. The present volume contains more than 1,600 abstracts of technical papers, research reports, books, codes, and conference proceedings. The abstracts are obtained from 98 technical journals, and from the publications of academic, professional, and governmental organizations in 23 countries. The staff of the *Abstract Journal* sincerely appreciates the efforts of those many individuals and organizations who have made valuable contributions to Volume 9.

National Information Service for Earthquake Engineering

The publication of the *Abstract Journal* is one of the principal activities of the National Information Service for Earthquake Engineering (NISEE). The information service was established in 1971 as a joint project of the University of California, Berkeley, and the California Institute of Technology. NISEE is sponsored by the National Science Foundation under a public service grant. The staff of the Earthquake Engineering Research Center at UC Berkeley is responsible for the publication of the *Abstract Journal.*

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We wish to thank those users who have commented on Volume 8. To assist us in further improving the journal, we continue to welcome such constructive criticism and suggestions.

R. C. DENTON, Editor

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Journals Surveyed

The journals listed below were surveyed for the purpose of collecting abstracts for this issue of the *Abstract Journal in Earthquake Engineering.* The Earthquake Engineering Research Center wishes to express its gratitude to the publishers of many of these journals for granting permission to reprint selected abstracts and summaries.

The publications which are indicated by an asterisk (*) are protected by copyright. Users of the *Abstract Journal* are advised to consult with the publishers of the individual journals on questions which might arise concerning copying, or otherwise reproducing, any abstracts, papers or reports which originally appeared in these publications.

*Applied Mathematical Modelling**
IPC Science and Technology Press Ltd.
Westbury House
P.O. Box 63, Bury Street
Guildford GU2 5BH, England

*Applied Ocean Research**
C.M.L. Publications
125 High Street
Southampton SO1 0AA, England

Asian Building and Construction
1913 Hanglung Centre
Causeway Bay
Hong Kong

Astronautics and Aeronautics
American Institute of Aeronautics and Astronautics, Inc.
1290 Avenue of the Americas
New York, New York 10019

Beton i zhelezobeton
Stroiizdat
Kalyaevskaya, 23a
Moscow 101442, GSP-4
Union of Soviet Socialist Republics

Bibliography of Seismology
International Seismological Centre
Newbury RG13 1LA, Berkshire, England

Bollettino di Geofisica
Osservatorio Geofisico Sperimentale
34016 Opicina, Italy

*Building and Environment**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

*Bulletin of the Association of Engineering Geologists**
8310 San Fernando Way
Dallas, Texas 75218

Bulletin of the Disaster Prevention Research Institute
Kyoto University
Kyoto, Japan

Bulletin of the Earthquake Research Institute
University of Tokyo
1-1, Yayoi 1-chome
Bunkyo-ku
Tokyo, Japan

Bulletin of the European Association for Earthquake Engineering
Institute of Earthquake Engineering and Engineering Seismology
University of Skopje
Skopje, Yugoslavia

Bulletin of the Indian Society of Earthquake Technology
Prabhat Press
Meerut, U.P., India

Bulletin of the Institution of Engineers (India)
8 Gokhale Road
Calcutta 700 020, India

Bulletin of the International Institute of Seismology and Earthquake Engineering
3-28-8 Hyakunin-cho
Shinjuku-ku
Tokyo, Japan

Bulletin of the New Zealand National Society for Earthquake Engineering
P.O. Box 243
Wellington, New Zealand

*Bulletin of the Seismological Society of America**
2620 Telegraph Avenue
Berkeley, California 94704

California Geology
California Division of Mines and Geology
P.O. Box 2980
Sacramento, California 95812

*Canadian Geotechnical Journal**
National Research Council of Canada
Ottawa K1A 0R6, Canada

*Canadian Journal of Civil Engineering**
National Research Council of Canada
Ottawa K1A 0R6, Canada

*Canadian Journal of the Earth Sciences**
National Research Council of Canada
Ottawa K1A 0R6, Canada

*Civil Engineering**
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017

*Civil Engineering**
Morgan-Grampian, Ltd.
30 Calderwood Street
Woolwich, London SE18 6QH, England

Civil Engineering in Japan
Japan Society of Civil Engineers
Yotsuya 1-chome, Shinjuku-ku
Tokyo 160, Japan

Civil Engineering Transactions
The Institution of Engineers (Australia)
11 National Circuit
Barton, A.C.T. 2600, Australia

*Closed Loop**
MTS Systems Corporation
Box 24012
Minneapolis, Minnesota 55424

*Computers and Structures**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

*Concrete International**
American Concrete Institute
P.O. Box 19150
Detroit, Michigan 48219

Deprem Arastirma Enstitusu Bulteni
Yuksel Caddesi No. 7/B
Yenisenir
Ankara, Turkey

*Disasters**
Pergamon Press
Maxwell House
Fairview Park
Elmsford, New York 10523

*Earthquake Engineering & Structural Dynamics**
John Wiley & Sons, Ltd.
Baffins Lane
Chichester, Sussex, England

Earthquake Notes
Eastern Section
Seismological Society of America
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

*Emergency Planning Digest**
Emergency Planning Canada
Ottawa K1A 0W6, Canada

*Engineering Geology**
Elsevier Scientific Publishing Co.
P.O. Box 211
1000 AE Amsterdam, The Netherlands

*Engineering Journal**
American Institute of Steel Construction
400 North Michigan Avenue
Chicago, Illinois 60611

*Engineering Structures**
IPC Science and Technology Press Ltd.
Westbury House
P.O. Box 63, Bury Street
Guildford GU2 5BH, England

*EOS Transactions, American Geophysical Union**
American Geophysical Union
2000 Florida Avenue, N.W.
Washington, D.C. 20009

*Experimental Mechanics**
Society for Experimental Stress Analysis
P.O. Box 277 Saugatuck Station
Westport, Connecticut 06880

*Geological Society of America Bulletin**
Geological Society of America, Inc.
3300 Penrose Place
Boulder, Colorado 80301

*Geoscience Canada**
Geological Association of Canada
Department of Earth Sciences
University of Waterloo
Waterloo N2L 3G1, Canada

*Géotechnique**
The Institution of Civil Engineers
P.O. Box 101
26-34 Old Street
London EC1P 1JH, England

*Geothermics**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

Gidrotekhnicheskoe stroitel'stvo
Ministry of Power and Electrification of the U.S.S.R.
2-ya Baumanskaya ulitsa
Moscow 107005, B-5
Union of Soviet Socialist Republics

Giornale del Genio Civile
Istituto Poligraficoe Zecca dello Stato
Piazza Verdi, 10
00100 Rome, Italy

Ingeniería Sísmica
Sociedad Mexicana de Ingeniería Sísmica, A. C.
Apartado Postal 70-227
Mexico 20, D.F., Mexico

*International Journal of Engineering Science**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

*International Journal of Fracture**
Sijthoff & Noordhoff International Publishers
P.O. Box 4
Alphen aan den Rijn, The Netherlands

*International Journal of Mechanical Sciences**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

*International Journal of Non-Linear Mechanics**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

*International Journal for Numerical and Analytical Methods in Geomechanics**
John Wiley & Sons, Ltd.
Baffins Lane
Chichester, Sussex, England

*International Journal for Numerical Methods in Engineering**
John Wiley & Sons, Ltd.
Baffins Lane
Chichester, Sussex, England

*International Journal of Pressure Vessels and Piping**
Applied Science Publishers, Ltd.
Ripple Road
Barking, Essex, England

*International Journal of Solids and Structures**
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, New York 10523

International Water Power & Dam Construction
IPC Electrical-Electronic Press Ltd.
Dorset House, Stamford Street
London SE1 9LU, England

*Journal of the Acoustical Society of America**
American Institute of Physics
335 East 45th Street
New York, New York 10017

*Journal of the American Concrete Institute**
American Concrete Institute
P.O. Box 19150
Detroit, Michigan 48219

*Journal of Applied Mechanics**
American Society of Mechanical Engineers
345 East 47th Street
New York, New York 10017

*Journal of Dynamic Systems, Measurement, and Control**
American Society of Mechanical Engineers
345 East 47th Street
New York, New York 10017

*Journal of the Engineering Mechanics Division**
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017

*Journal of Geophysical Research**
American Geophysical Union
2000 Florida Avenue, N.W.
Washington, D.C. 20009

*Journal of Geophysics**
Springer-Verlag
Postfach 105 280
D-6900 Heidelberg 1, Germany

*Journal of the Geotechnical Engineering Division**
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017

*Journal of the Hydraulics Division**
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017

Journal of the Institution of Engineers (India)
Civil Engineering Division
8 Gokhale Road
Calcutta 700 020, India

*Journal de Mécanique**
Tour 66,4
Place Jussieu
75230 Paris, Cedex 05, France

*Journal of Mechanical Engineering Science**
The Institution of Mechanical Engineers
P.O. Box 24
Northgate Avenue, Bury St. Edmunds
Suffolk IP32 6BW, England

*Journal of Physics of the Earth**
Center for Academic Publications Japan
4-16, Yayoi 2-chome
Bunkyo-ku
Tokyo 113, Japan

*Journal of the Prestressed Concrete Institute**
Prestressed Concrete Institute
20 North Wacker Drive
Chicago, Illinois 60606

*Journal of Research**
Public Works Research Institute
Ministry of Construction
2-28-32 Honkomagome
Bunkyo-ku
Tokyo, Japan

*Journal of Sound and Vibration**
Academic Press Inc., Limited
24-28 Oval Road
London NW1 7DX, England

*Journal of the Structural Division**
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017

*Journal of Structural Mechanics**
Marcel Dekker, Inc.
270 Madison Avenue
New York, New York 10016

*Journal of Testing and Evaluation**
200 North Bentalou Street
Baltimore, Maryland 21223

Journal of Tsing Hua University
Tsing Hua University
Peking, People's Republic of China

*Journal of the Waterway, Port, Coastal and Ocean Division**
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017

Magazine of Concrete Research
Cement and Concrete Association
Wexham Springs
Slough SL3 6PL, England

*Mass Emergencies**
Elsevier Scientific Publishing Company
P.O. Box 211
1000 AE Amsterdam, The Netherlands

*Matériaux et Constructions**
Secrétariat Général de la RILEM
12, rue Brancion
75737 Paris, Cedex 15, France

The Military Engineer
The Society of American Military Engineers
740 15th Street, N.W.
Washington, D.C. 20005

New Zealand Engineering
New Zealand Institution of Engineering
P.O. Box 12-241
Wellington, New Zealand

New Zealand Journal of Geology and Geophysics
Department of Scientific and Industrial Research
P.O. Box 9741
Wellington, New Zealand

*Nuclear Engineering and Design**
North-Holland Publishing Co.
P.O. Box 211
1000 AE Amsterdam, The Netherlands

Osnovaniya, fundamenty i mekhanika gruntov
Stroiizdat
2-ya Institutskaya, 6
Moscow 109389, Zh-389
Union of Soviet Socialist Republics

*Physics of the Solid Earth**
American Geophysical Union
2000 Florida Avenue, N.W.
Washington, D.C. 20009

*Proceedings**
The Institution of Civil Engineers
P.O. Box 101
26-34 Old Street
London EC1P 1JH, England

*Quarterly Reports**
Railway Technical Research Institute
Japanese National Railways
Kunitachi P.O. Box 9
Tokyo, Japan

*Science**
American Association for the Advancement of Science
1515 Massachusetts Avenue, N.W.
Washington, D.C. 20005

Seisan Kenkyu
No. 22, Roppongi 7-chome
Minato-ku
Tokyo 106, Japan

Soils and Foundations
Japanese Society of Soil Mechanics and Foundation Engineering
Sugayama Building 4F
Kanda Awaji-cho 2-23
Chiyoda-ku
Tokyo 101, Japan

Stroitel'naya mekhanika i raschet sooruzhenii
Stroiizdat
2-ya Institutskaya
Moscow 109389
Union of Soviet Socialist Republics

*The Structural Engineer**
The Institution of Structural Engineers
11 Upper Belgrave Street
London SW1X 8BH, England

*Surveying and Mapping**
American Congress on Surveying and Mapping
P.O. Box 601
Falls Church, Virginia 22046

*Technocrat**
Fuji Marketing Research Co., Ltd.
7F Dai-ni Bunsei Building
11-7, Toranomon 1-chome
Minato-ku
Tokyo 105, Japan

*Tectonophysics**
Elsevier Scientific Publishing Co.
P.O. Box 211
1000 AE Amsterdam, The Netherlands

*Transactions of the Architectural Institute of Japan**
Architectural Institute of Japan
2-19, 3 Chome Ginza
Chuoku
Tokyo, Japan

Transactions of the Japan Society of Civil Engineers
Yotsuya 1-chome
Shinjuku-ku
Tokyo 160, Japan

Voprosy inzhenernoi seismologii
Institute of Earth Physics
U.S.S.R. Academy of Sciences
Nauk Publishing House
Podsosenskii Per., 21
Moscow, K-62
Union of Soviet Socialist Republics

Zisin, Journal of the Seismological Society of Japan
Seismological Society of Japan
Earthquake Research Institute
University of Tokyo
Yayoi, Bunkyo-ku
Tokyo, Japan

1. General Topics and Conference Proceedings

1.1 General

● **1.1-1** Housner, G. W., **Earthquakes and earthquake engineering,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 1-22.

Crustal plate motions provide the source of the energy that produces earthquakes. The mechanism of earthquake generation involves four types of faulting. The size of an earthquake is described by the Richter magnitude, and an informative relationship exists between earthquake magnitude and fault length. An estimation of seismic hazard is made on the basis of the seismic history of a region; the estimation is used to construct seismic zoning maps. Special insensitive strong-motion earthquake accelerographs are used to record strong earthquake ground shaking and building motions. Earthquake accelerograms provide the basic data for the development of earthquake design procedures. Analyses of the dynamic response of structures to earthquake ground motions provide a tool for the seismic design of major structures. The response spectrum provides a basis for a simple method of seismic design. The application of the design spectrum is described, and its relation to building code requirements is discussed.

● **1.1-2** Lander, J. F., Alexander, R. H. and Downing, T. E., **Inventory of natural hazards data resources in the federal government,** U.S. National Oceanic and Atmospheric Admin. and U.S. Geological Survey, Boulder, Colorado, May 1979, 122.

This inventory outlines existing natural hazards data resources. Also described are offices that might serve a referral function, such as the departmental emergency coordinators; libraries; computerized search services; and public sales offices, such as the U.S. Government Printing Office and the National Technical Information Service. Supplied for each major dept. or agency in a single-sheet summary is information about the nature, scope, and sources of the data resource, and the structure of the resource (cost, available media, frequency of updating, access restrictions, etc.). References and addresses are also given. Earthquakes and tsunamis are among the hazards covered by this inventory.

● **1.1-3** Szuwalski, A., **Annotated bibliography of CERC publications,** Coastal Engineering Research Center, U.S. Army Corps of Engineers, Fort Belvoir, Virginia, June 1978, 126.

This bibliography includes a listing of publications issued by the Coastal Engineering Research Center (CERC) since 1963. Indexes of authors and keywords are also included.

● **1.1-4** Szuwalski, A. and Clark, L., **Bibliography of publications of the Coastal Engineering Research Center and the Beach Erosion Board,** Coastal Engineering Research Center, U.S. Army Corps of Engineers, Fort Belvoir, Virginia, June 1979, 142.

This bibliography covers literature published by the Coastal Engineering Research Center (CERC) and the Beach Erosion Board (BEB), predecessor to CERC. Publications issued by CERC since 1963 are listed with annotations accompanying each bibliographic entry. Indexes of authors and keywords are also included. Publications issued before 1963 by the BEB are listed without annotations. Annotations for the BEB reports can be found in CERC's Miscellaneous Paper 1-68, *Annotated Bibliography of BEB and CERC Publications.* A reference pertaining to the tsunami associated with the 1964 Alaskan earthquake is included.

● *See **Preface,** page v, for availability of publications marked with dot.*

● **1.1-5** Priestley, M. J. N., ed., **Research in civil engineering, 1972-1977,** *78-17,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Oct. 1978, 84.

This report describes research carried out at the Dept. of Civil Engineering, Univ. of Canterbury, between Jan. 1972 and Dec. 1978. Completed and current research topics are briefly described and referenced to a complete list of departmental and external publications.

● **1.1-6** Teng, T. L. and Lee, W. H. K., eds., **Earthquake research in China,** *Chinese Geophysics,* 1, *1-2,* 1978, 2 vols., 457.

These translation volumes consist of two parts: (1) translation of selected Chinese articles originally published in *Acta geophysica Sinica* and *Scientia geologica* from 1974-1977 and (2) invited papers and abstracts.

● **1.1-7** Japan Port and Harbour Research Inst., **List of publications, 1951-1977** [Yokosu-ka-shi], 1979, 166.

The publications are divided into the following subject areas: hydraulics and coastal engineering, soil mechanics and foundation engineering, structural mechanics and earthquake engineering, materials technology, design, port planning, dredging and construction equipment, and airport engineering.

1.2 Proceedings of Conferences

● **1.2-1 South Pacific Regional Conference on Earthquake Engineering, Proceedings of the Second,** New Zealand National Society for Earthquake Engineering, Wellington, 1979, 3 vols., 763.

The Second South Pacific Regional Conference on Earthquake Engineering was held at Victoria Univ. in Wellington, New Zealand, on May 8-10, 1979. The conference was sponsored by the New Zealand National Society for Earthquake Engineering, and was supported by the Earthquake and War Damage Commission and the New Zealand Inst. of Engineers. All the conference papers are individually abstracted or cited in this volume of the *AJEE.*

Volume 1: *A new proposal for estimating the expected maximum earthquake force at a nuclear power plant site,* Omote, S. et al.—*Seismotectonics and earthquake risk macrozoning in New Zealand,* Suggate, R. P.—*Estimations of the earthquake force appeared in an epicentral area in the case of large destructive earthquake,* Omote, S., Miyake, A. and Narahashi, H.—*Ground motion near causative fault of Kita-Tango earthquake of 1927,* Yoshikawa, S. et al.—*Seismic analysis of a highway bridge considering soil-structure interaction effects,* Iwasaki, T. and Kawashima, K.—*Foundations for capacity designed structures,* Taylor, P. W. and Williams, R. L.—*Floor response of yielding structures,* Kelly, T. E.—*Recent trends in Japanese research and development for earthquake-resistant buildings,* Aoyama, H. (summary only)—*Damage to civil engineering structures due to the near Izu-Ohshima earthquake of January 14, 1978,* Iwasaki, T. and Kawashima, K.—*Seismic risk and design criteria,* Hatrick, A. V.—*Earthquake risk analysis of transportation networks and their optimum urgent planning,* Hoshiya, M. and Ogasawara, Y.—*Recommendations for the design and construction of base isolated structures,* Blakeley, R. W. G. et al.—*Analysis and design of a base-isolated reinforced concrete frame building,* Megget, L. M.—*Design of an earthquake resisting building using precast concrete cross-braced panels and incorporating energy absorbing devices,* Matthewson, C. D. and Davey, R. A.—*Diagonal beam reinforcing for ductile frames,* Buchanan, A. H.

Volume 2: *A simplified method for assessing earthquake-induced soil liquefaction potential,* Ohashi, M.—*Seismic design of gravity retaining walls,* Elms, D. G. and Richards, R.—*Shaking table tests on a model retaining wall,* Sim, L. C. and Berrill, J. B.—*Evaluation of methods used in the determination of dynamic earth pressure,* Aggour, M. S. and Brown, C. B.—*The structural performance of houses in earthquakes,* Cooney, R. C.—*The development of the design of the ANZ head office building, Lambton Quay, Wellington,* Sharpe, R. D., Binney, J. R. and McNaughton, D. J.—*Computer-aided structural analysis and design of the 37-storey Los Angeles Bonaventure Hotel,* Nicoletti, J. P. et al.—*Earthquake forecasting, public policy and earthquake forecasting,* Lensen, G. J.—*Earthquake forecasting probability charts,* Rhoades, D. A.—*An evaluation method of system failure of industrial facilities under seismic loading,* Shibata, H. and Okamura, H.—*The seismic restraint of building services—a code of practice,* Upritchard, G. J.—*Dynamic performance of brick masonry veneer panels,* Priestley, M. J. N. et al.—*Cyclic load testing of two refined reinforced concrete beam-column joints,* Blakeley, R. W. G. et al.—*Inelastic response of interior R/C connections with slab,* Townsend, W. H.—*Tests on structural concrete beam-column joints with intermediate column bars,* Park, R. and Keong, Y. S.—*The behaviour of reinforced concrete beams under cyclic loading,* Fenwick, R. C. and Fong, A.

Volume 3: *Average estimates of the attenuation with distance of 5% damped horizontal acceleration response spectra,* Bentley, R. J.—*Influence of foundation compliance on the seismic response of bridge piers,* Priestley, M. J. N., Park, R. and Heng, N. K.—*Damage to lifeline systems in the city of Sendai caused by the 1978 Miyagiken-oki earthquake,* Katayama, T.—*Developments in the design of ductile reinforced concrete frames,* Paulay, T.—*The New Zealand strong motion earthquake recorder network,* Hefford, R. T. et al.—*Hysteretic dampers for the protection of structures from earthquakes,* Skinner, R. I. et al.—*Suspended ceilings: the seismic hazard and damage problem and some practical solutions,* Clark, W. D. and Glogau, O.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

A.—*An experimental study on liquefaction of sandy soils on a cohesive soil layer,* Asama, T. et al.—*Recent earthquake resistant design methods for different types of foundation in Japan,* Asama, T. et al.—*Seismic design of timber structures,* Mitchell, T. N.—*Evaluation of reinforcing bar mechanical splicing systems and recommendations for seismic design,* Raper, A. F. and Buchanan, B. W.—*The seismic zoning of Indonesia for normal building construction,* Bentley, R. J. and Zen, M. T.

● **1.2-2 Engineering design for earthquake environments,** *Institution of Mechanical Engineers Conference Publications 1978-12,* Mechanical Engineering Publications Ltd., Bury St. Edmunds, England, 1979, 241.

Engineering Design for Earthquake Environments, a conference held Nov. 7-9, 1978, in London, was sponsored by the Applied Mechanics Group of the Institution of Mechanical Engineers, the Japan Society of Mechanical Engineers, and the Society for Earthquake and Civil Engineering and Dynamics. The speakers were invited to review trends and assessment of seismic risk and ground motions for design purposes; the effects of soil and structure compliance in the design of mechanical engineering equipment; seismic-resistant design and qualification of equipment and plant components; and lessons learned from earthquake damage to plants. The conference proceedings includes brief discussions of some of the papers. All 25 papers presented at the conference are abstracted or cited in this volume of the *AJEE.*

The effects of earthquake loads on the design of pressure vessel shells, Cane, R. J. (C169/78)—*The main problems involved in the earthquake-resistance of nuclear power stations,* Kirillov, A. P. (C170/78)—*Electricity supply systems in earthquake areas,* Howells, D. A. (C171/78)—*The superposition problem of the response spectrum technique,* Zeman, J. L. (C172/78)—*Support motions for mechanical components during earthquakes,* Hadjian, A. H. (C173/78)—*Tests and calculations of reinforced concrete beams subjected to dynamic reversed loads,* Gauvain, J., Hoffmann, A. and Livolant, M. (C174/78)—*A rubber bearing system for seismic protection of structures,* Derham, C. J., Thomas, A. G. and Kelly, J. M. (C175/78)—*The problem of estimating seismic motions,* Long, R. E. (C176/78)—*A general procedure for estimating earthquake ground motions,* Hays, W. W. (C177/78)—*Evaluation of seismic analysis techniques for nuclear power plant piping and equipment,* Masri, S. F., Richardson, J. E. and Young, G. A. (C178/78)—*The effect of earthquakes on services and equipment in buildings and a proposed code of practice,* Upritchard, G. J. (C179/78)—*The aseismic design of structures and their foundations, including structure-fluid interaction,* Dungar, R. and Severn, R. T. (C180/78)—*Analysis and design of seismic Category I thin sheet structures,* Khan, A. S. et al. (C181/78)—*Protecting a turbo-generator installation against earthquakes,* Vint, J. V. (C182/78)—*A comparison of numerical methods for the aseismic design of mechanical systems,* Hitchings, D. and Beresford, P. J. (C183/78)—*On a model of earthquake ground motions for response analysis and some example of analysis through experiment,* Fujita, T. and Shibata, H. (C184/78)—*Seismic qualification of equipment mounted in CANDU nuclear power plants,* Heidebrecht, A. C. (C185/78)—*On the probabilistic prediction of seismic response,* Zbirohowski-Koscia, K. F. (C186/78)—*Seismic qualification of an emergency diesel generator and of its auxiliaries,* Kauffmann, F., Bonnefoy, A. and Fougeres, D. (C187/78)—*Seismic analysis of mechanical engineering equipment,* Lu, T. D., Patil, U. and Fischer, J. A. (C188/78)—*Seismic resistance of equipment and building service systems: review of earthquake damage, design requirements, and research applications in the USA,* Skjei, R. E., Chakravartula, B. C. and Yanev, P. I. (C189/78)—*Aseismic foundation system for nuclear power stations,* Plichon, C. and Jolivet, F. (C190/78)—*Statistical method estimating the seismic response of light secondary systems,* Kajimura, Y. and Shiraki, K. (C191/78)—*Response of rotating machinery subjected to seismic excitation,* Asmis, G. J. K. (C192/78)—*Seismic design of appendages under uncertainty,* Esteva, L. (C198/78).

● **1.2-3 Canadian Conference on Earthquake Engineering, Third,** Canadian National Committee for Earthquake Engineering et al., Montreal, 1979, 2 vols., 1388.

The Third Canadian Conference on Earthquake Engineering was held June 4-6, 1979, at McGill Univ. in Montreal. This conference was jointly sponsored by several organizations and institutions, including the Canadian National Committee for Earthquake Engineering and the Canadian Society for Civil Engineering. The conference focused attention on current practical problems of earthquake engineering in Canada. The proceedings comprise 54 papers in two volumes; all papers are abstracted or cited in this volume of the *AJEE.*

Volume 1: *Earthquakes and earthquake engineering,* Housner, G. W.—*Seismic risk mapping in Canada,* Basham, P. W. and Weichert, D. H.—*Review of seismic attenuation data,* Hasegawa, H. S., Milne, W. G. and Berry, M. J.—*Role of foundation soils in seismic damage potential,* Finn, W. D. L.—*La consolidation dynamique: une technique permettant de diminuer les risques de liquefaction de sols fins satures en cas de tremblement de terre* (in French), Gambin, M. P., Capelle, J.-F. and Dumas, J. C.—*Criteres d'analyse sismique des grands barrages* (in French), Bureau, G. J.—*Seismic response of buried pipelines,* Novak, M. and Hindy, A.—*Dynamic longitudinal response of a buried cavity of circular cross section,* Carriveau, A. R., Zanetti, J. M. and Edwards, R. B.—*Effet de l'interaction sol-structure sur le comportement dynamique de centrale nucleaire* (in French), Beliveau, J.-G., Ellyin, F. and Chandrasekhar, P.—*Dynamic response of surface and embedded rectangular foundations* *for body and surface wave excitations,* Ray, D. and Reed, R. C.—*Impedance approach and finite element method for seismic response analysis of soil-structure systems,* Chen, W. W. H. and Chatterjee, M.—*Code specifications and regulatory requirements for seismic design, analysis and testing of structures, component & systems,* Mehta, D. S. and Lee, K.—*Spectrum-compatible time-histories for seismic design of nuclear power plants,* Aziz, T. S. and Biswas, J. K.—*Earthquake fatigue effects on CANDU Nuclear Power Plant equipment,* Duff, C. G. and Heidebrecht, A. C.—*Earthquake analysis of a nuclear power station turbine building,* Jaeger, L. G. and Mufti, A. A.—*On simplified design methods for nonlinear dynamic mechanical systems,* Frick, T. M.—*Seismic qualification of pressure relief valves for a negative containment system,* Aziz, T. S., Duff, C. G. and Tang, J. H.—*Seismic response of equipment located within asymmetric building structures,* Ishac, M. F. and Heidebrecht, A. C.—*Probabilistic prediction of floor response spectra,* Chakravorty, M. K., Wong, A. Y. C. and Foster, D. C.—*Risk dependent seismic design,* Grigoriu, M.—*Seismic qualification by shake table testing,* Wilson, J. C., Tso, W. K. and Heidebrecht, A. C.—*Structural models in earthquake engineering,* Mirza, M. S., Harris, H. G. and Sabnis, G. M.—*Dynamic testing of civil engineering structures,* Rainer, J. H.—*Earthquake codes and design in Canada,* Heidebrecht, A. C.—*Earthquake resistant design and ATC provisions,* Newmark, N. M.—*Correlation of static and dynamic earthquake analysis of the National Building Code of Canada 1977,* Anderson, D. L., Nathan, N. D. and Cherry, S.—*Torsional provisions in building codes,* Tso, W. K. and Meng, V.

Volume 2: *Some problems related to the establishment of earthquake design force levels,* Derecho, A. T. and Iqbal, M.—*Establishment of ductility factor based on energy absorption and evaluation of present methods,* Cheng, F. Y., Oster, K. B. and Kitipitayangkul, P.—*Seismic design of buildings using a time-history method,* Humar, J. L.—*Systemes de resistance aux forces laterales dans les charpentes d'acier* (in French), Picard, A.—*Influence of P-delta effects on seismic design,* Montgomery, C. J.—*Mathematical modelling of the seismic response of a one story steel frame with infilled partitions,* Yanev, B. S. and McNiven, H. D.—*Seismic response of multistory frames clad with corrugated panels,* Ha, H. K. and Hassan, F.—*Pilot tests of composite floor diaphragms,* Porter, M. L. and Greimann, L. F.—*Seismic response of large-panel structures using limited-slip bolted joints,* Pall, A. S. and Marsh, C.—*Capacity design of earthquake resisting ductile multistorey reinforced concrete frames,* Paulay, T.—*Effect of wall strength on the dynamic inelastic seismic response of yielding wall-elastic frame interactive systems,* Fintel, M. and Ghosh, S. K.—*Earthquake response of steel frame-cracked concrete shear wall systems,* Kostem, C. N. and Branco, J. A.—*Seismic response of shear wall-frame systems,* Thomas, G. R. and Petalas, N.—*Nonlinear dynamic analysis of 2-D reinforced concrete building structures,* Otani, S.—*Selection of an optimum moment redistribution in seismic-resistant design of R/C ductile moment resisting frames,* Zagajeski, S. W. and Bertero, V. V.—*Buildings susceptible to torsional-translational coupling,* Pekau, O. A. and Gordon, H. A.—*Seismic response of multi-simple span highway bridges,* Zimmerman, R. M. and Brittain, R. D.—*Modified substitute structure method for analysis of existing buildings,* Yoshida, S. et al.—*Behaviour and analytical models of reinforced concrete columns under biaxial earthquake loads,* Otani, S., Cheung, V. W.-T. and Lai, S. S.—*Seismic characteristics of composite precast walls,* Mueller, P. and Becker, J. M.—*Selected precast connections: low-cycle behavior and strength,* Aswad, A.—*Bond characteristics of reinforcing bars for seismic loadings,* Hawkins, N. M. and Lin, I. J.—*Seismic behavior of concrete block masonry piers,* Hidalgo, P. A. et al.—*Earthquake of March 4, 1977 in Romania–damage and strengthening of structures,* Ifrim, M.—*Seismic design of industrial structures in Chile,* Arze-Loyer, E.—*Nonlinear seismic response analysis of a gravity monopod using MODSAP-IV,* Reddy, D. V., Arockiasamy, M. and Haldar, A. K.—*Seismic vulnerability of a water distribution system—a case study,* Pikul, R. R., Wang, L. R.-L. and O'Rourke, M. J.

● **1.2-4** Noor, A. K. and McComb, Jr., H. G., eds., **Trends in computerized structural analysis and synthesis,** *Computers & Structures,* Papers presented at Symposium on Future Trends in Computerized Analysis and Synthesis, **10,** *1/2,* Apr. 1979, 3–430.

This special issue of *Computers & Structures* features papers presented at the Symposium on Future Trends in Computerized Structural Analysis and Synthesis, held Oct. 30–Nov. 1, 1978, in Washington, D.C. The proceedings of the symposium is cited in Vol. 8 of the *AJEE* (see Abstract No. 1.2-55). The following papers pertinent to earthquake engineering are abstracted or cited in this volume of the *AJEE.*

Finite element dynamic analysis on CDC STAR-100 computer, Noor, A. K. and Lambiotte, Jr., J. J.—*A multi-microprocessor system for finite element structural analysis,* Jordan, H. F. and Sawyer, P. L.—*Computerized symbolic manipulation in structural mechanics—progress and potential,* Noor, A. K. and Andersen, C. M.—*Symbolic generation of finite element stiffness matrices,* Korncoff, A. R. and Fenves, S. J.—*CAL—a computer analysis language for teaching structural analysis,* Wilson, E. L.—*A standard computer graphics subroutine package,* Foley, J. D.—*An application of computer graphics to three dimensional finite element analyses,* Frey, A. E., Hall, C. A. and Porsching, T. A.—*A substructured frontal solver and its application to localized material nonlinearity,* Alizadeh, A. and Will, G. T.—*Mixed time integration schemes,* Wright, J. P.—*Static and dynamic analysis of Kirchhoff shells based on a mixed finite element formulation,* Talaslidis, D. and Wunderlich,

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

W.—*Condensation for mixed dynamic FE analysis of rotational shells,* Gould, P. L.—*Improved method of free vibration analysis of frame structures,* Basci, M. I., Toridis, T. G. and Khozeimeh, K.—*Adaptive approximations in finite element structural analysis,* Peano, A. et al.—*Drag method as a finite element mesh generation scheme,* Park, S. and Washam, C. J.—*Geometric structural modelling: a promising basis for finite element analysis,* Golden, M. E.—*On transient analysis of fluid-structure systems,* Bathe, K. J. and Hahn, W. F.—*Algorithms and software for in-core factorization of sparse symmetric positive definite matrices,* Rose, D. J. et al.

● **1.2-5** Saxena, S. K., ed., **Evaluation and prediction of subsidence,** Papers presented at International Conference on Evaluation and Prediction of Subsidence, American Society of Civil Engineers, New York, 1979, 594.

Held in Pensacola Beach, Florida, in Jan. 1978, the conference was sponsored by the American Society of Civil Engineers, the Society of Mining Engineers of AIME, the International Assn. of Hydrological Sciences, and the Illinois Inst. of Technology, with partial support provided by the National Science Foundation. The primary purpose of the conference was to bring together experts in geology, geotechnology, and groundwater hydrology from various parts of the world. In addition to 35 papers, the publication contains author and subject indexes. The following paper of interest to earthquake engineers is abstracted in this volume of the *AJEE: Subsidence earthquake at California oil field,* Lee, K. L.

● **1.2-6** **U.S. National Conference on Earthquake Engineering, Proceedings of the 2nd,** Earthquake Engineering Research Inst., Berkeley, California, 1979, 1171.

The 2nd U.S. National Conference on Earthquake Engineering, sponsored by the Earthquake Engineering Research Inst. with the cooperation of several other groups, was held at Stanford Univ., Stanford, California, on Aug. 22-24, 1979. The conference proceedings includes an author index to the papers presented at the conference. The following papers are abstracted or cited in this volume of the *AJEE.*

Session 3A-Risk Analysis: *A Bayesian seismic risk study of California,* Eguchi, R. T. and Hasselman, T. K.—*Comparative seismic hazard studies for the San Francisco Bay region,* Oliveira, C. S.—*Seismic risk analysis of northern Anatolia based on intensity attenuation,* Gurpinar, A. et al.—*Earthquake safety at the Lawrence Berkeley Laboratory,* Eagling, D. G.—*Probabilistic evaluation of seismic exposure,* Kulkarni, R. B., Sadigh, K. and Idriss, I. M.—*Damage prediction for earthquake insurance,* Sauter F., F.—*Variability of earthquake hazard assessments in the eastern U.S.,* Fischer, J. A.—*Seismic risk analysis in terms of acceleration response spectra,* Katayama, T.

Session 3B-Industrial Facilities: *Seismic analysis of oil refinery structures,* Kircher, C. A. et al.—*Vibration tests of full-scale liquid storage tanks,* Housner, G. W. and Haroun, M. A.—*Importance of vertical acceleration in the design of liquid containing tanks,* Marchaj, T. J.—*Seismic performance of piping systems supported by nonlinear hysteretic energy absorbing restrainers,* Lee, M. C. et al.—*Consideration of dynamic stress concentrations in the seismic analysis of buried structures,* Chen, P. C., Deng, D. Z. F. and Birkmyer, A. J.—*Shear stiffness degradation of tensioned reinforced concrete panels under reversing loads,* Perdikaris, P. C., Conley, C. H. and White, R. N.—*Seismic response of cracked cylindrical concrete structures,* Gergely, P. and Smith, J. K.—*Seismic response of elevated liquid storage tanks,* Lee, S. C. and Reddy, D. V.

Session 4A-Seismology and Geology: *Effects of nonuniform spontaneous rupture propagation on the level and duration of earthquake ground motion,* Das, S. and Richards, P. G.—*Data load estimation techniques for strong-motion networks,* Porter, L. D. and Real, C. R.—*Empirical data about local ground response,* Hays, W. W., Rogers, A. M. and King, K. W.—*Attenuation of strong-motion parameters in the 1976 Friuli, Italy, earthquakes,* Faccioli, E. and Agalbato, D.—*Prediction of nonstationary earthquake motions for given magnitude, distance, and specific site conditions,* Kameda, H. et al.—*Estimated building losses from U.S. earthquakes,* Wiggins, J. H.—*Measures of ground motion,* Sandi, H.—*An approximate method for estimating the strong motion earthquake spectra on bedrock,* Ishida, K.

Session 4B-Structural Engineering—Experimental Studies: *Possibilities and limitations of scale-model testing in earthquake engineering,* Krawinkler, H.—*An experimental investigation of the reinforcement requirements for simple masonry structures in moderately seismic areas of the U.S.,* Gulkan, P. and Mayes, R. L.—*Seismic behavior of masonry piers,* Hidalgo, P. A. and McNiven, H. G.—*Seismic behavior of diagonal steel wind bracing,* Clough, R. W. and Ghanaat, Y.—*Effects of beam strength and stiffness on coupled wall behavior,* Aristizabal-Ochoa, J. D., Shiu, K. N. and Corley, W. G.—*Large scale vibration testing of engineering structures,* Sterett, J. B. and Watson, C. E.

Session 5A-The Miyagi-Ken-Oki Earthquake of June 12, 1978: *Effect of the Miyagi-oki, Japan earthquake of June 12, 1978 on lifeline systems,* Kubo, K.—*Damage to highway bridges and other lifeline systems from the Miyagi-ken-oki, Japan earthquake of June 12, 1978,* Kuribayashi, E. et al.—*Building damage caused by the Miyagi-ken-oki Japan earthquake June 12, 1978,* Watabe, M.—*Statistical studies of low-rise Japanese building damage: the Miyagiken-oki earthquake of June 12, 1978,* Scawthorn, C., Yamada, Y. and Iemura, H.

● *See **Preface**, page v, for availability of publications marked with dot.*

Session 5B–Structural Engineering: *Towards a simple energy method for seismic design of structures,* McKevitt, W. E. et al.—*Explicit inelastic dynamic analysis and proportioning of earthquake-resistant reinforced concrete buildings,* Fintel, M. and Ghosh, S. K.—*Nonlinear overturning effects in a core-stiffened building,* Huckelbridge, Jr., A. A. and Christ, R. A.—*Cyclic end moments and buckling in steel members,* Jain, A. K. and Goel, S. C.—*The seismic response of simple precast concrete panel walls,* Becker, J. M. and Llorente, C.—*Reduction in earthquake response of structures by means of vibration isolators,* Tezcan, S. S. and Civi, A.—*The Alexisismon: an application to a building structure,* Ikonomou, A. S.

Session 6A–Public Policy and Economic Studies: *An examination of aseismic legislation for nonstructural components in essential facilities,* McGavin, G. L.—*Recertification of private sector buildings: the Dade County experience,* Warburton, R.—*Economic analysis of earthquake engineering investment,* Oppenheim, I. J.—*Acceptance of a social cost for human safety: a normative approach,* Pate, M.-E.—*A practical approach to damage mitigation in existing structures exposed to earthquakes,* Kustu, O.

Session 6B–Structural Engineering–Dynamics: *A statistical study of inelastic response spectra,* Newmark, N. M. and Riddell, R.—*Analysis of multiple degree of freedom systems with correlated and uncertain response spectra parameters,* Webster, F. A. and Benjamin, J. R.—*Identification of linear structural models from earthquake records,* McVerry, G. H., Beck, J. L. and Jennings, P. C.—*Step-by-step integration of linear structural systems considering uncertainty in the parameters,* Contreras, H.—*Some observations on the effective period and damping of randomly excited yielding systems,* Grossmayer, R. L. and Iwan, W. D.—*Seismic response of equipment in multi-story structures: response evaluation and test simulation,* Wilson, J. C. and Heidebrecht, A. C.—*Reliability of seismic-resistant frames designed by inelastic spectra,* Casciati, F., Faravelli, L. and Gobetti, A.

Session 7A–Geotechnical Engineering–Analytical Procedures: *Nonlinear soil dynamics by characteristics method,* Wylie, E. B. and Henke, R.—*Sensitivity of computed nonlinear effective stress soil response to shear modulus relationships,* Larkin, T. J. and Donovan, N. C.—*Seismic response of soft offshore soils—a parametric study,* Martin, G. R. et al.—*Dynamic response of horizontally layered systems subjected to traveling seismic waves,* Udaka, T., Lysmer, J. and Seed, H. B.—*Field evaluation of body and surface-wave soil-amplification theories,* Gazetas, G. and Bianchini, G.—*Earth pressures during earthquakes,* Prakash, S. and Nandakumaran, P.—*An overview of soil-structure interaction procedures with emphasis on the treatment of damping,* Kamil, H., Hom, S. and Kost, G.—*Earthquake induced deformations in earth dams,* Chaney, R. C.

Session 7B–Lifeline Engineering: *Recent developments in seismic analysis of buried pipelines,* Ariman, T. and Muleski, G. E.—*Seismic performance of spatially distributed engineering systems—a numerical algorithm,* Monzon-Despang, H.—*Seismic risk of underground lifeline systems resulting from fault movement,* Shinozuka, M. and Koike, T.—*Expected flow in a transportation network,* Fenves, S. J. and Law, K. H.—*Role of corrosion in water pipeline performance in three U. S. earthquakes,* Isenberg, J.—*The three-dimensional response of structures subjected to traveling Rayleigh wave excitation,* Werner, S. D. and Lee, L. C.

Session 8A–Risk Analysis: *SHA-based attenuation model parameter estimation,* Askins, R. C. and Cornell, C. A.—*The usefulness of ground motion duration in predicting the severity of seismic shaking,* McGuire, R. K. and Barnhard, T. P.—*Determination of seismic design parameters: a stochastic approach,* Savy, J. B.—*A statistical analysis of accelerogram peaks based upon the exponential distribution model,* Zsutty, T. and De Herrera, M.—*A probabilistic definition of effective acceleration,* Mortgat, C. P.—*On the regionalization of ground motion attenuation in the conterminous United States,* Chung, D. H. and Bernreuter, D. L.—*Earthquake risk and damage estimates for New Madrid,* Liu, B.-c. and Hsieh, C.-T.—*A probabilistic seismic damage model,* Del Tosto, R.—*Sensitivity analysis of uncertainty in seismic sources modeling on seismic hazard mapped parameters,* Mihailov, V.

Session 8B–Earthquake Engineering Reports from Several Countries: *Comparative tests on strengthened stone-masonry buildings,* Benedetti, D. and Castellani, A.—*Statistical survey of the performance of one standard-design type of high-rise reinforced-concrete shear-wall apartment buildings, in Bucharest, during the March 4, 1977, Romania earthquake,* Iordachescu, E. et al.—*Criteria for seismic design of low-rise brittle buildings in developing countries,* Razani, R.

Session 11A–Structural Design: *Component analysis—will it lead to safer, more economical structures?,* Englekirk, R. E.—*Inelastic behavior of steel braces under cyclic loading,* Popov, E. P.—*The rehabilitation of History Corner of the Stanford University Main Quad,* Holmes, W. T.—*Rehabilitation of buildings damaged by earthquakes,* Kulka, F., Teran, J. F. and Tai, J.—*Design considerations for plywood diaphragms in seismic zone 4,* Tissell, J. R.—*Study on aseismic capacity of a HiRC (highrise reinforced concrete) building referenced to newly proposed codes in Japan and U.S.A.,* Muto, K., Sugano, T. and Inoue, N.—*Earthquake response of three dimensional steel frames stiffened by open tubular concrete shear walls,* Kostem, C. N. and Heckman, D. T.

Session 11B-Geotechnical Engineering–Stability Considerations: *Determination of design earthquake for the dynamic analysis of Fort Peck Dam,* Marcuson III, W. F. and Krinitzsky, E. L.—*On the seismic behavior of loess soil foundations,* Minkov, M. and Evstatiev, D.—*Blast induced soil liquefaction,* Charlie, W. A., Shinn, J. and Melzer, S.—*Behavior of slopes in weakly cemented soils under seismic loading,* Sitar, N. and Clough, G. W.—*A probabilistic analysis of landslide potential,* Keeney, R. L. and Lamont, A.—*Experimental investigation of the dynamic response characteristics of an earth dam,* Abdel-Ghaffar, A. M. and Scott, R. F.—*Prediction of soil liquefaction potential during earthquakes,* Sherif, M. A. and Ishibashi, I.

Session 12A-Structural Design: *Seismic study of the George R. Moscone (Yerba Buena) Convention Center, San Francisco, California,* Tandowsky, S.—*Reconstruction of Margaret Jacks Hall, Stanford University,* Willsea, F.—*A documented vertical acceleration failure,* Wyllie, Jr., L. A. and Poland, C. D.—*Dynamic behavior of a pedestal base multistory building,* Stephen, R. M. and Wilson, E. L.—*Selected precast connections: low-cycle behavior and strength,* Aswad, A.—*Improving ductility of existing reinforced concrete columns,* Kahn, L. F. and Suriano, B. J.

Session 12B-Seismology and Geology: *The effectiveness of trenches and scarps reducing seismic energy,* Bolt, B. A. and May, T. W.—*Some effects of a surface dipping layer on structure and ground response in earthquakes,* Wojcik, G. L.—*A discussion of "non-linear" magnitude-frequency laws,* Grandori, E., Grandori, G. and Petrini, V.—*Simulation of strong earthquake motion with contained explosive line source arrays,* Bruce, J. R., Lindberg, H. E. and Abrahamson, G. R.—*Methods of investigating fault activity in the western Sierran foothills, California,* Harpster, R. E., Biggar, N. E. and Anttonen, G. J.—*Stochastic vs. deterministic effects in earthquakes,* Nur, A. and Kovach, R. L.—*Prediction feasibility of induced seismicity following impounding of reservoirs,* Guha, S. K. et al.

Special Session on Earthquake Engineering in China (bound separately): *Some engineering features of the 1976 Tangshan earthquake,* Yuxian, H.—*Empirical criteria of sand liquefaction,* Junfei, X.—*Field phenomena in meizoseismal area of the 1976 Tangshan earthquake,* Dasheng, C.

Additional Papers on the 1976 Tangshan Earthquake: *Experience in engineering from earthquake in Tangshan and urban control of earthquake disaster,* Yaoxian, Y. and Xihui, L.—*Earthquake damage to pipelines,* Shaoping, S.—*Damage in Tianjin during Tangshan earthquake,* Guoliang, J.

Session 5A (additional papers bound separately): *Miyagi-ken-oki, Japan earthquake of June 12, 1978: general aspects and damage,* Okubo, T. and Ohashi, M.—*Ground failures and damage to soil structures from the Miyagi-ken-oki, Japan earthquake of June 12, 1978,* Yamamura, K. et al.

● **1.2-7 Concrete design: U.S. and European practices,** *ACI Publication SP-59, CEB Bulletin 113,* Proceedings of ACI-CEB-PCI-FIP Symposium, American Concrete Inst., Detroit, Michigan, 1979, 346.

This conference was cosponsored by the American Concrete Inst., the Comite Euro-International du Beton, the Prestressed Concrete Inst., and the Federation Internationale de la Precontrainte. The symposium was held during the 1976 American Concrete Inst. Annual Convention in Philadelphia, Pennsylvania. A combined author and subject index is included in the conference proceedings. The following five papers, each abstracted or cited in this volume of the *AJEE,* are pertinent to the field of earthquake engineering.

General approach to safety, serviceability, and limit state philosophy–European Concrete Committee, Rowe, R. W. (SP 59-1)—*Loadings–CEB approach,* Mathieu, H. (SP 59-2)—*Limit states design for reinforced and prestressed concrete–CEB approach,* Macchi, G. (SP 59-4)—*Design of beams, deep beams, and corbels for shear–ACI 318-71 and revisions proposed by ACI Committee 426,* MacGregor, J. G. (SP 59-5)—*Shear strength of reinforced and prestressed concrete–CEB approach,* Thurlimann, B. (SP 59-6).

● **1.2-8 Soil mechanics in engineering practice,** Workshop held Mar. 26–30, 1979, Univ. of California, Berkeley, Continuing Education in Engineering, Univ. Extension, Univ. of California, Berkeley, 1979, 310.

This workshop was held at the Univ. of California, Berkeley, on Mar. 26–30, 1979. The sponsors of the workshop were the College of Engineering and the Continuing Education in Engineering, Univ. Extension, both of the Univ. of California, Berkeley, and the Geotechnical Division of ASCE. The following five papers from the workshop are pertinent to the field of earthquake engineering. These papers are not abstracted or cited in this volume of the *AJEE.*

Foundations for dynamic machine loadings, Richart, Jr., F. E.—*Foundations for auto shredders,* Richart, Jr., F. E. and Woods, R. D.—*Design of pile foundations,* Vesic, A. S.—*Laterally loaded piles,* Reese, L. C.—*Workshop on Foundation Studies for Deepwater Platforms,* McClelland, B. and Clausen, C. J. F., organizers.

● **1.2-9 The First Arab Seismological Seminar** (in English or Arabic), Seismological Unit, Foundation for Scientific Research, Baghdad [1979], 361.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

The First Arab Seismological Seminar was held in Baghdad on Dec. 18–20, 1978. The Foundation for Scientific Research in Iraq, the Federation for Arab Councils of Scientific Research, and the Union of Arab Geologists cosponsored the meeting. The aims of the seminar were to discuss and coordinate the activities of the Arab countries in the fields of seismology and earthquake engineering, and to explore the possibility of a regional network of seismological stations. Some of the papers in the volume are in Arabic; others are in English. None of the papers is abstracted individually in this volume of the *AJEE.*

● **1.2-10** Hudson, D. E., ed., **Natural disaster mitigation research,** Proceedings of the Indo-U.S. Workshop on Natural Disaster (Earthquake and Wind) Mitigation Research, California Inst. of Technology, Pasadena, 1979, 53.

The Indo-U.S. Workshop on Natural Disaster Mitigation Research, held in New Delhi on Dec. 13–16, 1978, was sponsored by the Indian government's Dept. of Science and Technology and the U.S. National Science Foundation and organized by the Univ. of Roorkee, India. The workshop addressed a variety of technical and scientific problems relevant to natural disaster mitigation, with the objective of identifying research programs mutually beneficial to India and the U.S. Workshop participants were grouped to study specific project topics; those projects pertinent to the field of earthquake engineering were Strong motion earthquake instrumentation array in the Shillong area, Investigation into methods of designing earth and rock-fill dams for earthquake motions, Generation of strong earthquake type ground motion by high explosive arrays, Strengthening of masonry buildings to withstand earthquake forces, and Programmed shake table facility. Recommendations for developing four research areas were suggested by the meeting participants. These recommendations are summarized in the proceedings volume.

● **1.2-11** Alarcon, E. and Brebbia, C. A., eds., **Applied numerical modelling,** Proceedings of the 2nd International Conference held at Madrid Polytechnic Univ., Spain, Sept. 1978, Pentech Press, London, 1979, 698.

This volume comprises the 58 papers presented at the Second International Conference on Applied Numerical Modelling, held at the Escuela Tecnica de Ingenieros Industriales de Madrid in Sept. 1978. Delegates from more than 20 countries attended the meeting. The proceedings includes papers on regional models, structural and fluid mechanics systems, numerical and computational techniques, bio-engineering, and transport problems. The following three papers, pertinent to the field of earthquake engineering, are abstracted or cited in this volume of the *AJEE: Solution of infinite dynamic problems by finite modelling in the time domain,* Cundall, P. A. et al.—*Solution of a building structures boundary-value problem,* Rosman, R.—*Problem oriented languages for finite element analysis,* Ferrante, A. J., de Lima, E. P. and Ebecken, N.

● **1.2-12** **Acoustical Society of America, 97th Annual Meeting, program and abstracts,** *The Journal of the Acoustical Society of America,* **65,** *Supp. No. 1,* Spring 1979, 142.

The 97th meeting of the Acoustical Society of America was held June 11–15, 1979, at the Massachusetts Inst. of Technology in Cambridge. This issue of *The Journal of the Acoustical Society of America* contains the program of the meeting, abstracts of papers presented, summaries of committee reports, and an author index to papers presented at the meeting. The following are the titles, authors' names, and paper numbers (in parentheses) of the abstracts relevant to earthquake engineering. These abstracts are not included in this volume of the *AJEE.*

Standards Committee S2 on Mechanical Shock and Vibration, Eshleman, R., Pusey, H. and Booth, G., chmn.—*Vibration software trends and availability,* Pilkey, W. D.(EE2)—*Measurement and analysis of the dynamics of mechanical structures,* Richardson, M.(EE3)—*Finite element analysis for the transient response of thin elastic spherical shells,* Singh, A. V.(EE4)—*The optimization of constrained layer damping applications,* Miles, R. N.(RR4)—*Utilization of the RKU equations to design constrained layer damping treatments,* Knighton, D. L. and Jones, D. I. G.(RR7)—*Vibration of cylindrical shells with and without ring-stiffening,* Eichelberger, E. C.(RR8)—*The transients of a multiresonant vibrator,* Skudrzyk, E. J. (RR9).

● **1.2-13** **Offshore Technology Conference—1979, Proceedings of Eleventh Annual,** Offshore Technology Conference, Dallas, Texas, 1979, 4 vols., 2769.

The conference was held in Houston, Apr. 30–May 3, 1979. It was sponsored by eleven international engineering and scientific societies. In addition to the four proceedings volumes, a separate volume includes a subject index, an author index, and a bibliographic information section. Those papers of relevance to earthquake engineering are abstracted or cited in this volume of the *AJEE.* The paper titles, paper numbers (in parentheses), and authors' names follow.

High-and-low-cycle fatigue behavior of prestressed concrete in offshore structures (OTC 3381), Gerwick, B. C. and Venuti, W. J.—*Summary of potential hazards and engineering constraints, proposed OCS Lease Sale No. 48, offshore southern California* (OTC 3398), Ploessel, M. R. et al.—*Re-examination of P-Y curve formulations* (OTC 3402), Stevens, J. B. and Audibert, J. M. E.—*Effects of soil-structure interaction on seismic response of a steel gravity platform* (OTC 3404), Veletsos, A. S. and Boaz, I. B.—*The*

● See ***Preface,*** *page v, for availability of publications marked with dot.*

development and demonstration of a strong motion seafloor earthquake measurement system (OTC 3462), Reece, E. W. and Ryerson, D. E.—*Anisotropic sand structure related to dynamic pore pressures* (OTC 3487), Arulanandan, K. et al.—*Cyclic static model pile tests in a centrifuge* (OTC 3492), Scott, R. F.—*Forced vibration tests of a deepwater platform* (OTC 3514), Ruhl, J. A. and Berdahl, R. M.—*Western Gulf of Alaska seismic risk* (OTC 3612), Pulpan, H. and Kienle, F.—*A sea-floor seismic monitoring network around an offshore oilfield platform and recording of the August 13, 1978 Santa Barbara earthquake* (OTC 3613), Henyey, T. L. et al.—*Observation of oscillation of a deep water platform and the ground during earthquakes* (OTC 3614), Ueda, S. and Shiraishi, S.—*Soil coupling of a strong motion, ocean bottom seismometer* (OTC 3615), Steinmetz, R. L. et al.—*Seismic, oceanographic, and reliability considerations in offshore platform design* (OTC 3616), Bea, R. G. and Akky, M. R.

● **1.2-14** Stuart, W. D. and Nur, A., co-organizers, **Fault Mechanics and Its Relation to Earthquake Prediction, Proceedings of Conference III,** convened under auspices of National Earthquake Hazards Reduction Program, 1-3 December 1977, *Open-File Report 78-380,* Office of Earthquake Studies, U.S. Geological Survey, Menlo Park, California, 1978, 680.

The conference, the third in a continuing series to be convened under the auspices of the Earthquake Hazards Reduction Program, was held at Stanford Univ., Stanford, California. Of the nineteen state-of-the-art papers included in the proceedings, four are pertinent to earthquake engineering and are listed below. These papers are not individually abstracted in this volume of the *AJEE. Implications of earthquake triggering and rupture propagation for earthquake prediction based on premonitory phenomena,* Brune, J. N.—*The June 10, 1975 Kurile Islands tsunami earthquake: an extended abstract,* Geller, R. J. and Shimazaki, K. (abstract only)—*Slow earthquakes and very slow earthquakes,* Pfluke, J. H.—*Earthquake precursory effects due to pore fluid stabilization of a weakening fault zone,* Rice, J. R. and Rudnicki, J. W.

● **1.2-15** McComb, Jr., H. G., comp., **Research in computerized structural analysis and synthesis,** *NASA CP-2059,* Research-in-progress papers presented at a symposium held at Washington, D.C., Oct 30-Nov. 1, 1978, Langley Research Center, U.S. National Aeronautics and Space Admin., Hampton, Virginia, 1978, 224.

A Symposium on Future Trends in Computerized Structural Analysis and Synthesis was held at Washington, D.C. on Oct. 30-Nov. 1, 1978. NASA Langley Research Center and the George Washington Univ. sponsored the symposium in cooperation with the National Science Foundation and the American Society of Civil Engineers. The purpose of the symposium was to provide a forum for structural technologists and computer hardware and software experts to examine recent developments and discuss trends in this rapidly advancing area of technology. This conference publication includes 17 symposium papers; 13 were presented at research-in-progress sessions and 4 at other sessions. The papers deal with five subjects: (1) potential of new computing systems and artificial intelligence (5 papers), (2) advances in numerical analysis (3 papers), (3) structural engineering software systems (1 paper), (4) adaptive finite element analysis and mesh design (2 papers), and (5) structural applications (6 papers).

Those papers of interest to earthquake engineers include: *Finite element analysis in a minicomputer/mainframe environment,* Storaasli, O. O. and Murphy, R. C.—*Finite element mesh configurations using isoenergetics and equalized energy levels,* Turke, D. J.—*Adaptation of a program for nonlinear finite element analysis to the CDC STAR 100 computer,* Pifko, A. B. and Ogilvie, P. L.—*On a new algorithm for time step integration of nonlinear systems,* Anderheggen, E. and Bazzi, G.—*Three-dimensional finite strip analysis of elastic solids,* Cheung, M. S. and Chan, M. Y. T.—*Structural analysis consultation using artificial intelligence,* Melosh, R. J., Marcal, P. V. and Berke, L.—*A direct element resequencing procedure,* Akin, J. E. and Fulford, R. E.—*Progressive failure of structures,* Khozeimeh, K. et al.—*The Lanczos algorithm with selective orthogonalization,* Parlett, B. N. and Scott, D. S. None of these papers are abstracted in this volume of the *AJEE.*

This publication is a companion volume to *Trends in a Computerized Structural Analysis and Synthesis* (see Abstract No. 1.2-55, *AJEE,* Vol. 8).

● **1.2-16** Ariman, T., Liu, S. C. and Nickell, R. E., eds., **Lifeline earthquake engineering-buried pipelines, seismic risk, and instrumentation,** *PVP-34,* American Society of Mechanical Engineers, New York, 1979, 285.

The Symposium on Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk and Instrumentation was held during the Third National Conference on Pressure Vessels and Piping, June 25-29, 1979, in San Francisco. The symposium was sponsored by the Task Force on Lifeline Earthquake Engineering of the Pressure Vessels and Piping Div. of the American Society of Mechanical Engineers. The titles and authors are listed below. All papers are abstracted or cited in this volume of the *AJEE.*

A review of the response of buried pipelines under seismic excitations, Ariman, T. and Muleski, G. E.—*Estimation of structural strains in underground lifeline pipes,* Shinozuka, M. and Koike, T.—*Seismic behavior of buried pipelines,* O'Rourke, M. J., Singh, S. and Pikul, R.—*Effects of local inhomogeneity on the dynamic response of pipelines,* Nelson, I. and Weidlinger, P.—*Structural analysis of*

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

buried reinforced plastic mortar pipe using the finite element method, Cole, B. W., Ritter, C. J. and Jordan, S.—*Dynamic yielding of tubings under biaxial loadings,* Lee, L. H. N. and Ng, D. H.—*Some aspects of seismic resistant design of buried pipelines,* Wang, L. R.-L.—*A finite element analysis of buried pipelines under seismic excitations,* Chen, C. C., Ariman, T. and Katona, M.—*Hydraulic transients in liquid-filled pipelines during earthquakes,* Young, F. M. and Hunter, S. E.—*Testing and analysis of buried piping under applied loads,* Niyogi, B. K. and Sethi, J. S.—*Seismic safety analysis of lifeline systems,* Mohammadi, J. and Ang, A. H.-S.—*Seismic risk and reliability of the California State Water Project,* Kiremidjian, A. S.—*Decision optimization of lifelines with multiple earthquake associated hazards,* Benjamin, J. R. and Webster, F. A.—*The practical use of risk analysis: yesterday, today and tomorrow,* Wiggins, J. H.—*On a new proposal of seismic instrumentation and trigger systems for industrial facilities,* Shibata, H.—*Instrument arrays for strong ground motion studies,* Iwan, W. D.—*Strong motion data management,* Brady, A. G.—*Bureau of Reclamation Strong Motion Instrumentation Program,* Viksne, A.—*Los Angeles and vicinity, California, strong motion accelerograph network: a progress report,* Anderson, J. G., Trifunac, M. D. and Teng, T. L.—*Strong motion studies in the central United States,* Herrmann, R. B. et al.

● **1.2-17 American Geophysical Union, Spring Annual Meeting, program and abstracts,** *EOS, Transactions of the American Geophysical Union,* **60,** *18,* May 1, 1979, 221–438.

The 1979 Spring Annual Meeting of the American Geophysical Union was held in Washington, D.C., May 28–June 1, 1979. This issue of *EOS* contains the preliminary program, abstracts of papers presented at the meeting, and an author index. Following are the titles and authors' names of the abstracts related to earthquake engineering. These abstracts are not included in this volume of the *AJEE.*

Seismicity in Baffin Bay, studied with a local land and ocean seismograph network, Reid, I., Falconer, R. K. H. and Stevens, A. E.—*Seismicity along the Rocky Mountain foreland in Alberta, Canada,* Wetmiller, R. J.—*Seismicity and tectonic stress in the southcentral Pacific,* Sverdrup, K. et al.—*Earthquake recurrence expectation for the contiguous United States,* Howell, Jr., B. F.—*Seismicity patterns related to the occurrence of interplate earthquakes off the coast of northeastern Japan,* Engdahl, E. R., Umino, N. and Takagi, A.—*The frequency-magnitude distribution in the double-planed seismic zone beneath Tohoku, Japan,* Anderson, R. N. et al.—*Distribution in space and time of b-values in the Adak seismic zone,* Price, S. J.—*Seismicity variations in the Makran region of Pakistan and Iran: relation to great earthquakes,* Quittmeyer, R. C.—*Seismicity, earthquake mechanisms and tectonics of the Bandar Abbas (Iran) region,* Chandra, U.—*Microearthquake surveys in the central and northern Philippines,* Acharya, H. K. and Fergusson, J. F.—*TS/TP anomalies at Monticello Reservoir, South Carolina,* Rastogi, B. K. et al.—*Short-term tilt anomalies preceding three local earthquakes near San Jose, California,* Iwatsubo, E. Y. and Mortensen, C. E.—*Spectral analysis of station residuals in total field magnetometer measurements on the San Andreas fault,* McPherron, R. L. et al.—*Pore pressure loading of critically stressed sawcut rock: implications for earthquake control,* Roeloffs, E. A. and Wang, H. F.—*Induced seismicity at Toktogul Reservoir, Kirgiz SSR, USSR,* Pavlov, V. D. et al.—*Induced seismicity at Nurek Reservoir in 1976 and inferred style of deformation,* Keith, C. M., Simpson, D. W. and Soboleva, O. V.—*Spatial and temporal patterns of induced seismicity at Nurek Reservoir, Tadjik SSR, USSR,* Simpson, D. W. and Negmutallaev, S. Kh.—*Induced seismicity studies at Monticello Reservoir, South Carolina,* Amick, D. C. et al.—*Semi-empirical approach to prediction of long-period ground motions from large earthquakes,* Kanamori, H.—*Measurement of fundamental mode frequencies, attenuations, and excitations from the 19 August 1977 Indonesian earthquake,* Buland, R. P.—*The relative effects of pore fluids on seismic attenuation and velocities,* Winkler, K. and Nur, A.—*Ultrasonic velocity and relative attenuation measurements in St. Peter's and Berea sandstones at 150°C with varying degrees of water saturation,* DeValbiss, J. and Nur, A.—*Static and dynamic moduli of sedimentary rocks,* Cheng, C. H., Johnston, D. H. and Toksoz, M. N.—*The reversible Griffith crack–a new mechanism for dilatancy,* Stevens, J. L. and Holcomb, D. J.

● **1.2-18 American Geophysical Union, Fall Annual Meeting, program and abstracts,** *EOS, Transactions of the American Geophysical Union,* **60,** *46,* Nov. 13, 1979, 801–982.

The 1979 Fall Annual Meeting of the American Geophysical Union was held in San Francisco, Dec. 3–7, 1979. This issue of the *EOS* contains the preliminary program, abstracts of papers presented at the meeting, and an author index. Following are the titles, authors' names, and paper numbers (in parentheses) of the abstracts related to earthquake engineering. These abstracts are not included in this volume of the *AJEE.*

Geodolite measurement of deformation in southern California 1971–1979, Savage, J. C. et al. (G34)—*Crustal structure and vertical crustal movements in Imperial Valley, California,* Lee, W. B. and Jackson, D. D. (G35)—*Deformation along the northwest margin of the southern California uplift,* Stein, R. S. (G36)—*Dry tilt anomalies in the central southern California uplift, 1977–1979,* Sylvester, A., Mowles, D. and Frischer, S. (G37)—*The Palmdale bulge—an alternate interpretation,* Jackson, D. D. and Lee, W. B. (G39)—*Further monitoring of the Pasadena, Goldstone, Owens Valley baselines by VLBI geodesy,* Niell, A.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

E. (G41)—*Recent temporal gravity changes in southern California,* Whitcomb, J. H. (G42)—*Gravity stable in southern California, 1976–1978,* Jachens, R. C. and Roberts, C. W. (G43)—*Geodetically derived strain at Shelter Cove, California,* Snay, R. A. and Cline, M. W. (G45).

Local studies of earthquake source characteristics in central California, Mueller, C. S., Geller, R. J. and Stein, S. (S1)—*Wideband near-field observations of aftershocks of the Diamond Valley, California earthquake of 04 September 1978,* Somerville, M., Peppin, W. and VanWormer, J. D. (S2)—*Global average attenuation measurements from surface waves and free oscillations and their implications,* Stein, S. et al. (S51)—*Seismic source functions and attenuation from local and teleseismic observations of the NTS events Jorum and Handley,* Hadley, D. M. and Helmberger, D. V. (S55)—*Attenuation in the eastern Great Basin from intensity and ground-amplitude data,* Arabasz, W. J. and Griscom, M. (S56)—*Regional modifications of ground motion attenuation functions,* Battis, J. C. (S58)—*Precursory seismicity, seismicity gaps and earthquake prediction studies at Lake Jocassee and Monticello Reservoir, S. C.,* Talwani, P. (S61)—*The mechanism of induced seismicity at Monticello Reservoir, South Carolina: in-situ studies at hypocentral depths,* Zoback, M. D. et al. (S62)—*Microseismicity associated with hydraulic fracturing of basement rocks,* Albright, J. N. et al. (S64)—*Seismicity, possibly induced by Lake Crowley, on the eastern front of the Sierra Nevada, California,* Toppozada, T. R. (S65)—*The Kariba Dam, Rhodesia seismicity (1959–1971) and earth tides,* Ford, P. and Mauk, F. (S66)—*Relocation of earthquakes in Koyna, India and identification of possible active faults,* Rastogi, B. K. and Talwani, P. (S67).

Sensory mechanisms for animal behavior before earthquakes, Buskirk, R. E., Frohlich, C. and Latham, G. V. (S68)—*A search for co-variance among seismicity, groundwater chemistry, and groundwater radon in southern California,* Hammond, D. E. et al. (S69)—*Meteorological noise in crustal gas emission relevant to earthquake prediction,* Klusman, R. W. and Webster, J. D. (S70)—*CH_4 content of geothermal gases before and after an earthquake,* Oremland, R. S. (S72)—*Seismicity trends in southern California,* Hutton, L. K., Minster, J. B. and Johnson, C. E. (S75)—*Investigations of seismic quiescence and microearthquakes along the southern San Andreas fault: Coachella Valley, California,* Leitner, B. J. et al. (S76)—*Oaxaca, Mexico, earthquake of 29 Nov. 1978: some spatio-temporal features of preceding and aftershock seismic activities,* Ponce, L. et al. (S77)—*Precursory seismicity: quiescence and clusters,* Habermann, R. E. (S78)—*A study of microearthquake activity preceding some moderate earthquakes in eastern Taiwan,* Tsai, Y. B., Lee, T. Q. and Liaw, Z. S. (S79)—*Search for precursors in the New Hebrides island arc: the August 17, 1979 earthquake (M_s = 6.2),* Isacks, B. L. et al. (S80)—*Seismotectonic setting of the Shumagin Islands region, Alaska: evidence for a seismic gap and a region of high seismic potential,* Davies, J. N. and House, L. (S83)—*Tree rings reveal Gulf of Alaska earthquakes in 1300, 1390, 1560, and 1899,* Beavan, J. et al. (S84)—*Seismotectonic regionalization of the Great Basin, and comparison of moment rates computed from Holocene strain and historic seismicity,* Greensfelder, R. W., Kintzer, F. C. and Somerville, M. R. (S85)—*Continued observation of transient velocity variations near Palmdale, California,* Leary, P. C. and Malin, P. E. (S86).

A preliminary study of the Coyote Lake earthquake of August 6, 1979 and its major aftershocks, Lee, W. H. K. et al. (S117)—*Observations of the Coyote Lake earthquake sequence of August 1979,* Uhrhammer, R. A. (S118)—*Strong-motion records from the Coyote Lake earthquake, California,* Joyner, W. B., Porter, L. D. and Perez, V. (S119)—*Near-field digital recordings of aftershocks from the Coyote Lake earthquake of August 6, 1979,* Fletcher, J. B. and Borcherdt, R. D. (S120)—*The Coyote Lake earthquake: 0.42 g acceleration from an S-P converted phase,* Angstman, B. G., Spudich, P. K. P. and Fletcher, J. (S121)—*Rupture propagation effects in the Coyote Lake earthquake,* Archuleta, R. J. (S122)—*Modeling the strong ground motions from the Coyote Lake earthquake,* Hadley, D. M. and Helmberger, D. V. (S123)—*Surface faulting accompanying the August 6, 1979 Coyote Lake earthquake,* Herd, D. G. et al. (S124)—*Ground cracks and afterslip observed following the 6 August, 1979 earthquake at Coyote Lake, California,* Coppersmith, K. J., Rogers, T. H. and Savage, W. U. (S125)—*Creep on the Calaveras fault near Coyote Lake,* Raleigh, B., Stuart, W. and Harsh, P. (S126)—*Multi-wavelength geodetic measurements southeast of the Coyote Lake, California earthquake August 6, 1979,* Slater, L. E. and Langbein, J. (S127)—*Geodolite measurements near the epicenter of the Coyote Lake earthquake of August 6, 1979,* King, N. E. et al. (S128)—*Seismic activity associated with the August 6, 1979 Coyote Lake earthquake,* Bakun, W. H. (S129)—*Historic seismic activity and the 1979 Coyote Lake sequence,* Bufe, C. G., Bakun, W. H. and McEvilly, T. V. (S130)—*Microearthquake clustering preceding the Coyote Lake earthquake,* Savage, W. U. and Ellsworth, W. L. (S131)—*The source characterization of the Coyote Lake earthquake of August 6, 1979 from synthesis of teleseismic body waves,* Nabelek, J. and Toksoz, M. N. (S132)—*Temporal variations in teleseismic P travel times to stations near the August 6, 1979, Coyote Lake earthquake,* Stauber, D. A. and Evans, J. R. (S133)—*Soil-gas radon-concentration data recorded at the time of the Coyote Lake earthquake of August 6, 1979,* King, C. Y. (S136)—*A search for reports of unusual animal behavior prior to the Coyote Lake earthquake of 6 August 1979,* Lott, D. F. et al. (S137).

Aftershock locations of the 14 March 1979 M_S = 7.6 Petatlan, Guerrero, Mexico, earthquake, Suarez, F. and Reichle, M. (S151)—*The 1979 Guerrero, Mexico earthquake: source mechanism analysis from digital data,* Reichle, M. S., Orcutt, J. A. and Priestley, K. (S152)—*An*

● *See **Preface**, page v, for availability of publications marked with dot.*

intermediate depth earthquake beneath Tibet: source characteristics of the event of September 14, 1976, Chen, W.-P. et al. (S155)—*The August 16, 1931 Texas earthquake,* Dumas, D. B., Dorman, H. J. and Latham, G. V. (S157)—*A microearthquake survey of northeastern Sonora, Mexico,* Natali, S., Gish, D. and Sbar, M. L. (S158)—*Analysis of the 4 February 1976 Chino Valley, Arizona earthquake,* Eberhart-Phillips, D. M. et al. (S159)—*New laboratory measurements of permeability and electrical resistivity of crystalline rocks,* Coyner, K. B., Brace, W. F. and Walsh, J. B. (T70)—*Electrical resistivity changes in Tuffs,* Morrow, C. and Brace, T. F. (T71)—*Some physical properties of fault gouges at high pressure,* Chin, H.-p. et al. (T72)—*In situ stress measurements near the San Andreas fault, Palmdale, California,* Dahlgren, J. P. et al. (T99)—*Magnetic field monitoring of tectonic stress, southern California,* Williams, F. J. and McWhirter, J. L. (T106)—*Seismic studies at the Mt. Hood volcano, northern Cascade Range, Oregon,* Green, S. M., Weaver, C. S. and Iyer, H. M. (T191).

● **1.2-19 International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process, Proceedings** (Simposio Internacional sobre el Terremoto de Cuatemala, del 4 de febrero de 1976 y el Proceso de Reconstruccion, Memorias, in Spanish or English), n.p. [Guatemala, 1978], 2 vols.

The symposium was held May 13–15, 1978, in Guatemala City. The Inst. de Fomento de Hipotecas Aseguradas and the Centro de Estudios Mesoamericanos sobre Tecnologia Apropiada were the two initiators of the symposium, and, along with several other groups, sponsored the meetings. The papers presented at the meetings were divided into four major areas: seismology, geology, structural engineering, and socioeconomic problems. The following papers, pertinent to earthquake engineering, are cited or abstracted in this volume of the *AJEE.* Paper numbers are given in parentheses following the authors' names.

Volume I

Geology: *Plate tectonic framework of Middle America and Caribbean regions and prospects for earthquake prediction,* Sykes, L. R. (1)—*Tectonic framework of the Caribbean region: a historical review* (in Spanish), Dengo, G. (2)—*Tectonic significance of surface faulting related to the 4 February 1976 Guatemala earthquake,* Plafker, G. (3)—*Geological history of the Motagua Valley and of the Motagua fault system* (in English and Spanish), Donnelly, T. W. (4)—*Tectonics of the Middle America trench offshore Guatemala,* Ladd, J. W. et al. (5)—*Quaternary faulting along the Caribbean-North American plate boundary in Central America,* Schwartz, D. P., Cluff, L. S. and Donnelly, T. W. (6)—*Surface faulting and afterslip along the Motagua fault in Guatemala,* Bucknam, R. C., Plafker, G. and Sharp, R. V. (7)—*Urban geologic problems associated with the Mixco fault zone,* Bilodeau, S. W. (8)—*Unheeded geological warnings from the 1976 Guatemala earthquake,* Bonis, S. (9)—*Frictional characteristics of serpentinite from the Motagua fault zone in Guatemala,* Dengo, C. A. and Logan, J. M. (10)—*Liquefaction-caused ground failure during the February 4, 1976, Guatemala earthquake,* Hoose, S. N., Wilson, R. C. and Rosenfeld, J. H. (11)—*Study on talus slipping in ravines in Guatemala City* (in Spanish), Koose S., F. (12)—*Earthquake-induced landslides from the February 4, 1976 Guatemala earthquake and their implications for landslide hazard reduction,* Harp, E. L., Wieczorek, G. F. and Wilson, R. C. (13).

Socioeconomic Problems: *National emergency urban reconstruction plan (100 days plan)* (in Spanish), Rivera E., H. M. and Serrano, J. A. (15)—*The process of reconstruction in Guatemala* (in Spanish), Balcarcel J., M. A. and Orellana A., O. R. (16)—*Supervised practical work and reconstruction: an experience of the School of Engineering, University of San Carlos of Guatemala* (in Spanish), Barrientos, C. and Charnaud, B. (17)—*Human settlements and their relation with the effects of the February 4th., 1976 earthquake in Guatemala* (in Spanish), Chavarria S., F. (18)—*La Carolingia: a case of post-earthquake urban settlement* (in Spanish), von Hoegen, M. (19)—*Earthquake loss accumulation control,* Berz, G. (20)—*Cost evaluation and estimates of damages caused by the 4 February 1976 Guatemala earthquake on houses built under F.H.A. insurance* (in Spanish), Bonilla P., H. R. (21)—*Price evolution in building materials following the February 4, 1976 earthquake* (in Spanish), Peralta, C. and Rodolfo, J. (23)—*Project for educational investment in the area affected by the February 4th., 1976 earthquake* (in Spanish), Gonzalez, H. and Serrano, J. A. (24)—*Development and social effects of the Guatemalan earthquake,* Carmack, R. M. (25)—*Essay on evaluation of general economic repercussions of the earthquake in one of the most affected areas* (in Spanish), Cerezo R., A. (26)—*Work performed in the investigation program of aseismic materials for popular housing—Faculty of Architecture of the University of San Carlos* (in Spanish), Aguilar A., E. (27)—*Roofs of tin in El Quiche; an analysis of a reconstruction program in the highlands of Guatemala,* Earle, D. M. (28)—*Issues faced in programming Guatemala disaster rehabilitation assistance,* Rogers, D. L. (29)—*Towards a new strategy of rural development: adequate technology and the 1976 earthquake* (in Spanish), Caceres, R. and Asturias, J. (30)—*Earthquake injuries related to housing in a Guatemalan village—aseismic construction techniques may diminish the toll of deaths and serious injuries,* Glass, R. I. et al. (31)—*The reconstruction of Guatemala and improved adobe* (in Spanish), Gandara G., J. L. (33)—*Rationale, design and methodology for a longitudinal and cross cultural study of the post impact phases of a major national disaster,* Bates, F. L. et al. (34)—*Effects of the February 4, 1976 earthquake on human settlements in Guatemala* (in

● *See* ***Preface****, page v, for availability of publications marked with dot.*

Spanish), von Hoegen, M. (35)—*Issues for a national earthquake hazards reduction plan,* Steinbrugge, K. V. et al. (37).

Volume II

Seismology: *Seismological aspects of the Guatemala earthquake of February 4, 1976,* Kanamori, H. and Stewart, G. S. (38)—*Distribution of aftershocks following the Guatemala earthquake of 4 February 1976 and its tectonic aspects—interplate and intraplate seismic activity,* Matumoto, T. and Latham, G. (39)—*Seismicity of the North Anatolian fault, Turkey,* Ozaydin, K. and Erguvanli, A. (40)—*The earthquake prediction program in the U.S.,* Hamilton, R. (41)—*Aftershocks and secondary faulting associated with the 4 February 1976 Guatemalan earthquake* (in Spanish), Langer, C. J., Bollinger, G. A. and Henrisey, R. F. (42)—*Seismological aspects of the Guatemalan earthquake of February 4, 1976,* Tocher, D., Turcotte, T. and Hobgood, J. (43)—*Guatemalan strong-motion earthquake records,* Knudson, C. F. and Perez, V. (44)—*Sensitivity of the seismic hazard predictions for a site in Guatemala,* Kiremidjian, A. S. and Shah, H. C. (45)—*Seismic hazard mapping for Guatemala,* Kiremidjian, A. S., Shah, H. C. and Zsutty, T. C. (46)—*Applying the lessons learned in the 1976 Guatemalan earthquake to earthquake-hazard-zoning problems in Guatemala* (in Spanish), Espinosa, A. F., Asturias, J. and Quesada, A. (47)—*A simple method for incorporating the uncertainty of attenuation and spectral amplification in seismic risk analysis,* Hasselman, T. K. and Eguchi, R. T. (48)—*Relations between magnitude and ground acceleration for long distance earthquakes,* Fiedler, G. (49)—*Energy analysis and simulation of the Guatemala earthquake, 4 February 1976,* Alexander, Jr., J. F. (50).

Structural Engineering: *Soil-structure interaction for buildings subjected to earthquakes,* Veletsos, A. S. (51)—*The determination of earthquake design criteria,* Jennings, P. C. and Housner, G. W. (52)—*Recommendations for the elaboration of an antiseismic design code for Guatemala* (in Spanish), Ventura, C. E. (53)—*Damage in Guatemala City and vicinity due to the February 4, 1976, earthquake,* Husid, R. and Arias B., J. (54)—*Dynamic earth pressure determination,* Aggour, M. S. (55)—*Geological-seismological factors for specifying motions in the design of future dams in Guatemala,* Krinitzsky, E. L. (56)—*Practical earthquake resistant design of building structures,* Degenkolb, H. J., Wosser, T. D. and Wyllie, Jr., L. A. (57)—*Approximate seismic dynamic design based on basic first mode shapes,* Teal, E. J. (58)—*The behavior of different structural systems in concrete buildings during the Guatemalan earthquake* (in Spanish), Hermosilla, J. J. (59)—*Basis for the formulation of a seismic design code for El Salvador* (in Spanish), Colindres S., R. (60)—*Bridge and highway damage resulting from the 1976 Guatemala earthquake,* Cooper, J. D. (61)—*Causes of failure in damaged bridges during the February 4th, 1976 earthquake in Guatemala* (in Spanish), Percheron, J. C. (62)—*Metropolitan Cathedral of Guatemala—damages caused by the 1976 earthquake and its restoration* (in Spanish), Mondorf, P. E. and Asturias, J. (63)—*Seismic design of reinforced masonry for Guatemala* (in Spanish), Rossell S., C. (64)—*Analysis of vertical adobe walls* (in Spanish), Vargas N., J. (65)—*Strengthening existing bridges to increase their seismic resistance,* Degenkolb, O. H. (66)—*Bearings for earthquake resistant structures,* Xercavins, P. (67)—*The anti-seismic joint in pre-fabrication—a new industrial structural frame system,* Gatti, A. (68)—*Reconstruction and repair after the strong earthquake of March 4, 1977, produced in Bucharest, Romania,* Ifrim, M. (69)—*Introduction to the dynamics of discrete systems,* Marini, A. A., Augenti, N. and Santosuosso, A. (71)—*Aseismic design of reinforced concrete columns,* Cismigiu, A. I. and Dogaru, L. C. (72).

● **1.2-20** Jaeger, T. A. and Boley, B. A., eds., **International Conference on Structural Mechanics in Reactor Technology, Transactions of the 5th,** North-Holland Publishing Co., Amsterdam, 1979, 14 vols.

The conference was organized by the International Assn. for Structural Mechanics in Reactor Technology, the Commission of the European Communities, Bundesanstalt fur Materialprufung, and the U.S. Nuclear Regulatory Commission, along with several other organizations, and was held Aug. 13-17, 1979, in Berlin. The papers are arranged into a set of volumes according to the technical divisions of the conference. The volume titles are Vol. A: Introduction, General Contents, Authors Index; Vol. B: Thermal and Fluid/Structure Dynamics Analysis; Vol C: Analysis of Reactor Fuel and Cladding Materials; Vol. D: Structural Analysis of Reactor Fuel Elements and Assemblies; Vol. E: Energetics and Structural Dynamics in Fast Reactor Accident Analysis; Vol. F: Structural Analysis of Reactor Core and Coolant Circuit Structures; Vol. G: Structural Analysis of Steel Reactor Pressure Vessels; Vol. H: Structural Engineering of Prestressed Reactor Pressure Vessels; Vol. J: Loading Conditions and Structural Analysis of Reactor Containment; Vols. K(a) and K(b): Seismic Response Analysis of Nuclear Power Plant Systems; Vol. L: Materials Modeling and Inelastic Analysis of Metal Structures; Vol. M: Methods for Structural Analysis; and Vol. N: Thermal, Materials Engineering, and Structural Mechanics Problems of Future Fusion Reactor Power Plants.

The majority of papers pertinent to earthquake engineering are found in Vols. K(a), K(b), and M. Titles and authors' names of papers from these three volumes either abstracted or cited in this volume of the *AJEE* are as follows.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Vol. K(a) Seismic Response Analysis of Nuclear Power Plant Systems

Session K 1. Ground Motion: *Analyses on various parameters for the simulation of three-dimensional earthquake ground motions,* Watabe, M. and Tohdo, M. (K 1/1)—*Generation of simulated three-dimensional earthquake ground motions,* Watabe, M., Chiba, O. and Tohdo, M. (K 1/2)—*Primary variables influencing generation of earthquake motions by a deconvolution process,* Idriss, I. M. and Akky, M. R. (K 1/3)—*Phase characteristics of earthquake accelerogram and its application,* Ohsaki, Y. et al. (K 1/4)—*Input criterion for seismic analysis of nuclear power plants,* Gupta, D. C., Agrawal, P. K. and Singh, S. (K 1/6)—*Hysteresis behaviour of soils and rocks,* Hueckel, T. and Nova, R. (K 1/7)—*A model for soil behavior under monotonic and cyclic loading conditions,* Dafalias, Y. F. (K 1/8)—*On the effects of using wide range earthquakes,* Cecconi, S. et al. (K 1/9)—*A class of models for identification and simulation of earthquake ground motions,* Oliver, R. M. and Pister, K. S. (K 1/10).

Session K 2. Risk Analysis I: *Probabilistic evaluation of the SSE design spectrum for a nuclear power plant site: a case study,* Wheaton, R. et al. (K 2/3)—*A method for the estimation of the probability of damage due to earthquakes,* Alderson, M. A. H. G. (K 2/4)—*On a method of evaluation of failure rate of equipment and pipings under excess-earthquake loadings,* Shibata, H. and Okamura, H. (K 2/6)—*KTA 2201—Seismic design standards in the Federal Republic of Germany,* Philip, G. and Bork, M. (K 2/7)—*The MCE (maximum credible earthquake)—an approach to reduction of seismic risk,* Asmis, G. J. K. and Atchison, R. J. (K 2/8).

Session K 3. Risk Analysis II: *Systems analysis methods used in the Seismic Safety Margins Research Program,* Cummings, G. E. and Wells, J. E. (K 3/2)—*Expert opinion encoding in seismic hazard analysis,* Mortgat, C. P., Campbell, K. W. and Bernreuter, D. L. (K 3/4)—*Soil structure interaction analysis for the US NRC Seismic Safety Margins Research Program,* Johnson, J. J. (K 3/6)—*Major structural response methods used in the Seismic Safety Margins Research Program,* Chou, C. K., Lo, T. Y. and Vagliente, V. N. (K 3/7)—*Subsystem response determination for the US NRC Seismic Safety Margins Research Program,* Johnson, J. J. (K 3/8)—*Definition of component and structural fragility for use in the Seismic Safety Margins Research Program,* Dong, R. G. (K 3/9)—*Reserve seismic capacity determination of a nuclear power plant braced frame with piping,* Nelson, T. A. (K 3/10).

Session K 4. Design Concepts: *On fundamental concept of anti-earthquake design of equipment and pipings,* Shibata, H. and Kato, M. (K 4/1)—*Integrated structural design of nuclear power plants for high seismic areas,* Rieck, P. J. (K 4/2)—*Alternative structural systems for high density fuel storage racks in existing facilities,* Reed, J. W., Webster, F. A. and Sun, P. C. (K 4/4)—*Probabilistic seismic fluid-structure interaction of floating nuclear plants platforms,* Arockiasamy, M., Thangam Babu, P. V. and Reddy, D. V. (K 4/7).

Session K 5. Soil-Structure Interaction I: *Travelling wave effects in soil-structure interaction,* Wolf, J. P. and Obernhuber, P. (K 5/1)—*Comparison of soil-structure interaction by different ground models,* Takemori, T. et al. (K 5/5)—*Torsional structural response from free-field ground motion,* Lam, P. C. and Scavuzzo, R. J. (K 5/6)—*Seismic design method for arbitrary propagating waves,* Ettouney, M. M., Brennan, J. A. and Aguero, A. A. (K 5/7).

Session K 6. Soil-Structure Interaction II: *Soil structure interaction analyses by different methods,* Waas, G. and Weber, W. (K 6/1)—*The influence of uplift and sliding nonlinearities on seismic response of a small test reactor building,* Cofer, L. J. et al. (K 6/4)—*Structure-to-structure interaction analysis for a nuclear power plant,* Mueller, C. and Furrer, H. (K 6/5)—*Building-soil-building interaction in seismic analysis of nuclear power plants,* Del Grosso, A., Stura, D. and Vardanega, C. (K 6/6)—*Investigation of the influence of interaction of two adjacent structures on their responses,* Gantayat, A. N. et al. (K 6/8)—*Non-linear analysis of a deeply embedded power plant building subjected to earthquake load,* Mukherjee, S. N. (K 6/9).

Session K 7. Underground Structures: *Earthquake response of nuclear reactor building deeply embedded in soil,* Masao, T. et al. (K 7/1)—*Seismic response comparisons for an embedded high temperature gas-cooled reactor (HTGR) on a high seismic site,* Schlafer III, W., Tow, D. and Johnson, J. J. (K 7/2)—*Seismic stresses in buried piping of arbitrary configuration,* Deans, J. J. and Tang, J. H. K. (K 7/3)—*Seismic design of long underground structures,* Pagay, S. N. and Loceff, F. (K 7/4)—*Analytical and experimental investigation of the dynamic response of underground nuclear power plants,* Howard, G. E. and Ibanez, P. (K 7/5)—*Seismic response analysis for a deeply embedded nuclear power plant,* Chen, W. W. H., Chatterjee, M. and Day, S. M. (K 7/6)—*Inelastic seismic analysis of a deeply embedded reinforced concrete reactor building,* Celebi, M., Chatterjee, M. and Mark, K. (K 7/7)—*Experimental and analytical studies of a deeply embedded reactor building model considering soil-building interaction (Part I),* Tanaka, H., Ohta, T. and Uchiyama, S. (K 7/8)—*Seismic response of the 'cut-and-cover' type reactor containments considering nonlinear soil behavior,* El-Tahan, H. and Reddy, D. V. (K 7/9).

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

Vol. K(b) Seismic Response Analysis of Nuclear Power Plant Systems

Session K 8. Response of Structures: *Towards safe and economic seismic design of cooling towers of extreme height,* Kratzig, W. B. and Meskouris, K. (K 8/2)—*Response of a nonlinear system to various spectral excitation time decompositions,* Curreri, J. et al. (K 8/3)—*Critical seismic response of nuclear reactors,* Drenick, R. F. et al. (K 8/4)—*Nonlinear analysis of a BWR reactor building subjected to both thermal and earthquake loadings,* Muto, K. et al. (K 8/5)—*Fatigue analysis method for seismic structural response,* Kurosaki, A. and Kozeki, M. (K 8/6)—*Seismic response of a structure subjected to rotational base excitation,* Guilinger, W. H., Shah, V. N. and Bohm, G. J. (K 8/7)—*Combination of torsional, rotational and translational responses in the seismic analysis of a nuclear power plant,* Morrone, A. and Sigal, G. B. (K 8/8)—*Mutual pounding of adjacent structures during earthquakes,* Wolf, J. P. and Skrikerud, P. E. (K 8/9).

Session K 9. Floor Response Analysis: *Equipment response spectra for nuclear power plant systems,* Sackman, J. L. and Kelly, J. M. (K 9/1)—*On the seismic design spectra for heavy components and comparisons with the usual FRS techniques,* Cecconi, S., Giuliano, V. and Lazzeri, L. (K 9/2)—*On upperbound instructure response spectra,* Atalik, T. S. (K 9/3)—*Floor response spectra considering elasto-plastic behaviour of nuclear power facilities,* Kawakatsu, T. et al. (K 9/4).

Session K 10. Response of Piping and Equipment I: *Effect of energy absorbing supports on seismic pipe stresses,* Powell, G. H. and Row, D. G. (K 10/1)—*Comparison of multiple support excitation solution techniques for piping systems,* Leimbach, K.-R. and Sterkel, H. P. (K 10/2)—*"Missing mass" correction in modal analysis of piping systems,* Powell, G. H. (K 10/3)—*Residual load method for modal analysis of piping systems subjected to seismic excitation,* Krause, G. (K 10/4)—*Design of prequalified support systems subjected to dynamic loads,* Raheja, R. D., Cho, F. L. and Meligi, A. E. (K 10/6).

Session K 11. Response of Piping and Equipment II: *Arguments in favour of structures, systems and equipment seismic qualification by analysis,* Cambien, R. B. and Hennart, J. C. (K 11/2)—*Investigation on the design damping values for seismic analysis of nuclear power plant piping systems,* Shibata, H. et al. (K 11/3)—*On seismically induced vibrations of pressure vessels with cutouts and cracks,* Tezduyar, H. T., Ariman, T. and Lee, L. H. N. (K 11/4)—*Nonlinear transient dynamic response of pressure relief valves for a negative containment system,* Aziz, T. S., Duff, C. G. and Tang, J. H. K. (K 11/5)—*Seismic response analysis of nuclear power plant auxiliary mechanical equipment,* Lin, C.-W. (K 11/6)—*Seismic interaction effects for steam generators in CANDU 600 MWe nuclear power plants,* Aziz, T. S. and Duff, C. G. (K 11/7)—*Coupled lateral-torsional response of equipment mounted in CANDU nuclear power plants,* Ishac, M. F. and Heidebrecht, A. C. (K 11/8)—*Seismic analysis of category I crane structures,* Liu, T. H., Loceff, F. and Anderson, P. H. (K 11/9)—*Seismic design of cableways: a CAD approach,* Lazzeri, L., Agrone, M. and Strona, P. P. (K 11/10)—*Seismic and accident analysis of electrical machinery,* Filippi, G. et al. (K 11/11).

Session K 12. Reactor Core and Fluid Related Structures: *Two-dimensional vibration test and its simulation analysis for a horizontal slice model of HTGR core,* Muto, K., Motohashi, S. and Kuroda, K. (K 12/2)—*Forced vibration test of 1/5 scale model of CANDU core,* Muto, K., Kuroda, K. and Kasai, Y. (K 12/3)—*Seismic analysis of the reactor assembly of a 1000 MWe-LMFBR pool reactor,* Yang, C. C. and Kraus, S. (K 12/4)—*A study of structural attachments of a pool type LMFBR vessel through seismic analysis of a simplified three dimensional finite element model,* Ahmed, H. U. and Ma, D. (K 12/5)—*A three-dimensional computer code for the nonlinear dynamic response of an HTGR core,* Subudhi, M. et al. (K 12/6)—*Evaluation of seismic movements of a pebble bed reactor core as basis for shaking experiments* (in German), Glockner, H.-J., Kemter, F. and Schmidt, G. (K 12/7)—*Explicit evaluation of the apparent fluid mass at the vibration of fluid filled cylindrical tanks,* Fischer, D. F. (K 12/8)—*Experimental seismic test of fluid coupled co-axial cylinders,* Chu, M., Lestingi, J. F. and Brown, S. J. (K 12/9)—*Dynamic pressures in annulus-shaped pressure suppression pools of boiling water reactors generated by earthquake ground motions,* Bedrosian, B., Ettouney, M. and Brennan, J. (K 12/11).

Session K 13. Dynamic Testing and Qualification: *Tests and calculation of the seismic behaviour of concrete structures,* Gauvain, J. et al. (K 13/1)—*Low level earthquake testing of the HDR: comparisons of calculations and measurements for the reactor building,* Jehlicka, P., Malcher, L. and Steinhilber, H. (K 13/2)—*Low level earthquake testing of the HDR: comparisons of calculations, and measurements for mechanical equipment,* Jehlicka, P., Malcher, L. and Steinhilber, H. (K 13/3)—*Forced vibration test of BWR type nuclear reactor buildings considering through soil coupling between adjacent buildings,* Mizuno, N. et al. (K 13/4)—*Seismic qualification of General Electric test reactor safety-related valves,* Kircher, C. A., Reed, J. W. and Hoggatt, D. (K 13/5)—*Field vibration test results and design for reactor coolant piping systems of ATR "FUGEN,"* Igarashi, T., Arai, K. and Fujita, K. (K 13/7)—*Vibrational characteristics of primary reactor coolant system,* Shiraki, K. et al. (K 13/8)—*Experimental and analytical studies on aseismic design of ventilation ducts,* Suzuki, K. et al. (K 13/9)—*The results of dynamic tests on 1:10*

● *See **Preface**, page v, for availability of publications marked with dot.*

model of containment for nuclear reactor, Donten, K. et al. (K 13/10).

Vol. M Methods for Structural Analysis

Further developments of capabilities in the program ANSR for nonlinear finite element analysis, Mondkar, D. P. and Powell, G. H. (M 1/4)—*The computer program system for structural design of nuclear power plant* (in German), Aihara, S. et al. (M 1/5)—*Coupled damage modes (CDM) plasticity models for the simulation of complex materials used in reactors,* Dubois, J., Bianchini, J. C. and de Rouvray, A. (M 2/5)—*Implementation of endochronic theory for concrete with extension to include cracking,* Powell, G. H., de Villiers, I. P. and Litton, R. W. (M 2/6)—*Membrane versus shell type elements in F.E. analysis of box type buildings,* Canetta, G. (M 3/4)—*Super element model development and analysis on the Mark I torus structure,* Hua, L.-C. (M 3/6)—*Study of an axisymmetric model for the parametric analysis of a 3D complex steel structure,* Morel, A. et al. (M 3/7)—*Comparison between a 3D photoelastic model and an axisymmetric finite element calculus,* Morel, A. et al. (M 3/8)—*A thin shell dynamic transient non-linear analysis program,* Crutzen, Y. (M 5/9).

Penalty methods in finite element analysis of fluids and structures, Malkus, D. S.—*Dynamic analysis of buried structures subjected to shock loads,* Khatua, T. P., Pattanayak, A. K. and Gupta, A. K. (M 6/6)—*A numerical method for complex structural dynamics in nuclear plant facilities* (in German), Zeitner, W. (M 6/7)—*Implicit treatment of the large deformation response of inelastic solids with slide-lines,* Hallquist, J. O. (M 6/8)—*Quasi-Newton iteration in non-linear structural dynamics,* Geradin, M. and Hogge, M. A. (M 7/1)—*Linear dynamic analysis by hybrid displacement finite element models* (abstract only), Brandt, K. and Wissmann, J. W. (M 7/3)—*A method of solution of the eigenproblems of large structural systems in an arbitrarily specified range,* Orkisz, J. and Wrana, B. (M 7/4)—*Modal analysis and estimation of the calculation errors* (in German), Krings, W. (M 7/6)—*The development of time-history design criteria for uncertain transient loads,* Benjamin, J. R. (M 8/3)—*An interior collocation method for vibration of a rectangular plate carrying attached mass,* Patel, Y. A. (M 10/2)—*The use of an equivalent homogeneous half-space in soil-structure interaction analyses,* Holzlohner, U. (M 10/3)—*Some considerations on the dynamic structure-soil-structure interaction analysis,* Matthees, W. (M 10/3a)—*Quasi-nonlinear dynamic analysis,* Meyer, C. (M 10/4)—*Approximations for dynamic modeling,* Wu, S. T., Chiu, K. D. and Odar, E. (M 10/5)—*Stochastic finite element structural models,* Contreras, H. and Scholl, R. E. (M 10/6)—*Nonlinear response to the multiple sine wave excitation of a softening-hardening system,* Koplik, B., Subudhi, M. and Curreri, J. (M 10/7).

● **1.2-21** Chin, M. W., ed., **Proceedings of First Caribbean Conference on Earthquake Engineering,** Council of Caribbean Engineering Organizations and Univ. of the West Indies, St. Augustine, Trinidad, 1979, 574.

The conference, held Jan. 9–12, 1978, in Port-of-Spain, Trinidad, was sponsored by the Council of Caribbean Engineering Organizations, the Assn. of Professional Engineers of Trinidad & Tobago, the Univ. of the West Indies, the Trinidad and Tobago Bureau of Standards, and UNESCO. Included in the publication are 28 papers and an author index. All the papers are abstracted or cited in this volume of the *AJEE;* the paper titles and authors' names follow.

Seismicity, Risk Analysis and Zoning: *Earthquake parameters for engineering design in the Caribbean,* Tomblin, J.—*A surface wave study of source mechanisms of southeastern Caribbean earthquakes,* Morgan, F. D. and Aki, K.—*The 14 August 1977 earthquake near Trinidad,* Aspinall, W. P.—*An engineering risk analysis for Jamaica and Trinidad,* Pereira, J. and Gay, D.—*Physical development and associated seismic risk in Jamaica,* McDonald, F. J. and Turnovsky, J.—*Seismic problems in Brazil,* Valenzuela, L.—*Estimating earthquake risk in Jamaica,* Shepherd, J. and Aspinall, W. P.—*Preliminary analysis of seismic risk in the Lesser Antilles and Trinidad and Tobago,* Taylor, L. O., Aspinall, W. and Morris, P.

Dynamics of Soils: *Site effects in earthquake-resistant design,* Seed, H. B.—*Probabilistic assessment of site dependent design spectra in Trinidad,* Taylor, L. O. and Faccioli, E.—*Effects of overconsolidation and K_0 conditions on the liquefaction characteristics of sands,* Ishihara, K. and Takatsu, H.—*Establishment of equivalent linear model and site period of a soil profile,* Oweis, I. and Dobry, R.—*Seismic analysis of a complex industrial structure including soil structure interaction effect,* Gupta, S. P., Gupta, M. K. and Arya, A. S.—*Pile behaviour in earthquakes,* Buch, A.

Structural Analysis and Design: *Design and ductility of shear walls,* Degenkolb, H. J. and Wyllie, Jr., L. A.—*Earthquake resistant structures in the Caribbean: design practice, costs and problems,* Key, D.—*Earthquake analysis of multi-storey car parking structures,* Chin, M. W. and Bailey, K. A.—*Earthquake resistant design of earth retaining structures,* Nandakumaran, P.—*Effectiveness of rectangular ties as confinement steel,* Sheikh, S. A. and Uzumeri, S. M.—*An economic approach for seismic design: research to practice,* Tarpy, Jr., T. S., McCreless, C. S. and Lindsey, S. D.—*Current earthquake resistant structural design in Jamaica,* Adams, A. D.—*Proposals for more realistic force levels for earthquake resistant design in the Caribbean and their effect on structural load bearing masonry particularly in Barbados,* Rothwell, M. A.—*Low income housing in seismic zones,* Eaton, K. J.—*Externally reinforced concrete*

● *See* ***Preface****, page v, for availability of publications marked with dot.*

block walls, Wolde-Tinsae, A. M., Tso, W. K. and Heidebrecht, A. C.—*Recent earthquake damages and earthquake resistant construction of small buildings in India,* Gupta, S. P.

Codes and Regulations: *Earthquake engineering—design philosophy and codes,* Degenkolb, H. J.—*Earthquake resistant design and construction code for buildings in India,* Gupta, S. P.—*Development of a revised seismic code for the West Indies,* Chin, M. W.

● **1.2-22 Panamerican Conference on Soil Mechanics and Foundation Engineering, Sixth** (in English, Spanish, or Portuguese), American Regional Conference, International Society for Soil Mechanics and Foundation Engineering, Lima, Peru, 1979, 2 vols.

The conference was held in Lima from Dec. 2–7, 1979. The following papers, because of their relevance to earthquake engineering, are abstracted or cited in this volume of the *AJEE.*

Volume I: *Study on the stability of landslide N°5 in the Tablachaca reservoir at the Mantaro hydroelectric plant* (in Spanish), Novosad, S., Barvinek, R. and de la Torre Sobrevilla, M.—*Seismic stability of a proposed 55 meter high tailings dam at Chicrin, Peru,* Prieto-Portar, L. A. and Velarde S. M., J. L.—*Dynamic properties of soils in tailings dams* (in Spanish), Troncoso, J. H.

Volume II: *Performance of cylindrical oil tanks founded in a seismic area of soil treated by compaction piles,* Bhandari, R. K. M.—*Peculiarities of the seismic resistant analysis of earth dams with pervious gravelly shells* (in Spanish), Bolognesi, A. J. L.—*Dynamic behaviour of fluvio-alluvial soils of Lima* (in Spanish), Carrillo Gil, A.—*Preliminary tectonic, seismic and geologic considerations for earthquake design for Lima, Peru,* Deacon, R. J., Couch, R. W. and Repetto, P. C.—*Liquefaction failure of tailings dams resulting from the near Izu Oshima earthquake, 14 and 15 January 1978,* Marcuson III, W. F., Ballard, Jr., R. F. and Ledbetter, R. H.—*Analysis of vibratory behavior of machine foundations and finite element analysis for vibrations of surrounding ground,* Sams, C. E. and Browning, M. Y.—*Seismic risk and seismicity of the north-east region of Venezuela* (in Spanish), Tapia Galvan, M.—*Resonant column tests on Puerto Cabello sand* (in Spanish), Tinoco, F. H. and Sanabria Sucre, A. G.—*Liquefaction potential of a sand under static and dynamic loadings,* Townsend, F. C.—*Relationship between cyclic shear strength determined by triaxial and simple shear tests,* Weaver, J. J. and Roth, W. H.—*Foundations under pulling loads in residual soil—analysis and application of the results of load tests,* Barata, F. E. et al.—*Horizontal loaded piers at the Sao Paulo city porous clay* (in Portuguese), Rogerio, P. R. and Ricco, M. F.—*Study of the modulus of elasticity of a compacted soil,* Clemence, S. P. and Micnhimer, T. L.—*Effect of compaction on the behaviour of residual soils* (in Spanish), De Fries, K., Prusza, Z. and Choudry, T.

● **1.2-23** Lundgren, R., ed., **Behavior of deep foundations,** *ASTM STP 670,* American Society for Testing and Materials, Philadelphia, 1979, 609.

This publication contains papers presented at a symposium sponsored by the ASTM Committee D18 on Soil and Rock for Engineering Purposes and held in Boston on June 28, 1978. Also included in the publication is a subject index. The following papers of relevance to earthquake engineering are abstracted or cited in this volume of the *AJEE. Design and evaluation of load tests on deep foundations,* Reese, L. C.—*Design of high-performance prestressed concrete piles for dynamic loading,* Gerwick, Jr., B. C. and Brauner, H. A.—*Static and cyclic axial load tests on a fully instrumented pile,* Lu, T. D., Fischer, J. A. and Miller, V. G.—*Cyclic pile load testing—loading system and instrumentation,* Lu, T. D., Miller, V. G. and Fischer, J. A.—*Field tests on vertical piles under static and cyclic horizontal loading in overconsolidated clay,* Price, G.—*Horizontal subgrade reaction estimated from lateral loading tests on timber piles,* Robinson, K. E.—*Stress and deformation in single piles due to lateral movement of surrounding soils,* Wang, M. C., Wu, A. H. and Scheessele, D. J.

● **1.2-24 National Conference on Earthquakes and Related Hazards: Earthquake Prediction, Reaction and Response to Prediction, Hazard Reduction, Public Policy,** Council of State Governments, Lexington, Kentucky, 1978, 79.

Sponsors of the invitational conference held at Boulder, Colorado, Nov. 16–18, 1977, were the Council of State Governments with the cooperation of the Natural Hazards Research and Applications Information Center, Inst. of Behavioral Science, Univ. of Colorado. Representatives from federal, state, and local governments attended, along with a number of scientists from the academic and private research communities and others from public interest groups and the private sector. The conference was part of a two-year project being conducted by the Council of State Governments and financed by a grant from the National Science Foundation. The project is aimed at identifying policy issues which public officials may face as a result of an anticipated increasing ability of scientists to predict earthquakes. The project is concerned not just with earthquakes but with related hazards such as floods, fires, ground failures, and tsunamis. It will look at earthquake problems in the context of a comprehensive approach by public officials to natural and manmade hazards as well as emergencies of other kinds. It will also look at intergovernmental roles and relations and the role of the private sector in its examination of policy issues and potential efforts to reduce hazards.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

This report contains the conference program, a list of the conference participants, hazard loss maps for the nine most destructive natural hazards in the United States, and a progress report on the implementation of an Earthquake Hazard Reduction Program of the federal government. In addition, the report includes summaries of conference presentations and discussions relating to earthquake prediction; validation of earthquake predictions, issuance of warnings, and anticipated reaction; and risk assessment and hazard reduction.

● **1.2-25 International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings**, NEM Chand & Bros., Roorkee, India, 1979, 878.

The conference was held at the Univ. of Roorkee from Oct. 23-25, 1979. Papers presented at the conference covered the static and dynamic aspects of such topics as the finite element method, the finite difference method, optimization techniques, nonlinear analysis, vibrations and stability, and interaction problems as applied to the fields of structural, environmental, geotechnical, and transportation and highway engineering. Because of their relevance to earthquake engineering, the papers listed below are abstracted or cited in this volume of the *AJEE.*

Computer applications in an international consulting environment, Agrawal, K. M., Katramadakis, T. and Thom, A. L.—*Linear & nonlinear dynamics of cable supported systems,* Gambhir, M. L. and Batchelor, B. de V.—*Efficient numerical models for nonlinear analysis of braced frames,* Jain, A. K.—*Numerical methods for nonlinear dynamic structural analysis,* Thakkar, S. K.—*Vibration analysis of circular cylindrical cantilevered structures using axisymmetric finite elements,* Chandrasekaran, A. R. and Singhal, N. C.—*Influence of different types of mass matrices on vibration characteristics of two dimensional problems,* Chandrasekaran, A. R.—*Non-linear dynamic response analysis by minimization of the total potential dynamic work,* Buchholdt, H. A.—*Vibration of a model tower,* Ross, C. T. F.—*Efficient strategies in nonlinear implicit structural dynamics,* Geradin, M. and Hoggs, M.—*Structure dependent short duration combisweep accelerogram,* Bicanic, N.—*Finite difference analog for thick plates subjected to impulsive loading,* Eshpuniyani, B. L.—*A simple but efficient FEM-version for pipe vibration and instability,* Pramila, A.

Non-linear finite element analysis of pre-fabricated shear walls, Radhakrishnan, R., Santhakumar, A. R. and Swamidurai, S.—*Computer aided inelastic analysis of R.C. frames,* Sharma, S. S., Jain, P. C. and Trikha, D. N.—*Nonlinear finite element analysis of reinforced concrete coupled shear walls,* Santha Kumar, A. R.—*Simplified computer analysis of shear wall-frame building,* Paramasivam, P. and Sham, K. M.—*Analysis of core wall structures by finite element method,* Ahamad, V. and Ganesan, T. P.—*Effect of shear deformability of vertical joints on the structural response of prefabricated shear wall system,* Chakrabarti, S. C. and Nayak, G. C.—*A discrete stiffener element for doubly-curved shells,* Rao, T. V. S. R. A., Loganathan, K. and Gallagher, R. H.—*Analysis of conical shell foundation on elastic subgrade,* Jain, V. K., Nayak, G. C. and Jain, O. P.—*Simple boundary elements in soil-structure interaction applications,* Wood, L. A.—*Computer applications in the design of machine foundations,* Krishnaswamy, N. R., Nair, P. G. B. and Kanderphole, B. N.—*Parametric analysis of laterally loaded concrete piles in different soils using boundary elements,* Parikh, S. K. and Pal, S. C.

● **1.2-26 Conference reports presented at the Conference on Disasters and the Small Dwelling, Oxford, England, April 1978,** *Disasters, 3, 3,* 1979, 243-265.

Contained in this issue of *Disasters* are several reports presented at the conference. The titles of those reports relevant to earthquake engineering follow: Land-use planning, vulnerability and the low-income dwelling; Scenario for a housing improvement program in disaster-prone areas; The interface between earthquake planning and development planning: a case study and critique of the reconstruction of Huaraz and the Callejon de Huaylas, Ancash, Peru, following the 31 May 1970 earthquake; The reconstruction of Friuli—emergency versus long term planning. None of these reports are individually abstracted in this volume of the *AJEE.*

● **1.2-27** Uyeda, S., Murphy, R. W. and Kobayashi, K., eds., **Geodynamics of the Western Pacific,** *Advances in Earth and Planetary Sciences 6,* Center for Academic Publications Japan, Japan Scientific Societies Press, Tokyo, 1979, 592.

This publication contains papers presented at the Proceedings of the International Conference on Geodynamics of the Western Pacific-Indonesian Region held in Tokyo on Mar. 13-17, 1978. Also included in the publication are geographical and subject indexes. Those papers of relevance to earthquake engineering are listed below. None of the papers are abstracted in this volume of the *AJEE.*

Seismicity, gravity and tectonics in the Andaman Sea, Verma, R. K., Mukhopadhyay, M. and Bhuin, N. C.—*Focal mechanisms and tectonics in the Taiwan-Philippine region,* Seno, T. and Kurita, K.—*Recent tectonics of Taiwan,* Wu, F. T.—*Tectonics of the Ryukyu island arc,* Kizaki, K.—*Seismic activity and pore pressure across island arcs of Japan,* Fuji, N. and Kurita, K.—*Aseismic belt along the frontal arc and plate subduction in Japan,* Yamashina, K., Shimazaki, K. and Kato, T.—*Tsunamicity of Sanriku depends on subduction tectonics,* Adams, W. M.—*Significant* *eruptive activities related to large interplate earthquakes in the northwestern Pacific margin,* Kimura, M.

● 1.2-28 Brebbia, C. A., Gould, P. L. and Munro, J., eds., **Environmental forces on engineering structures,** Halsted Press, John Wiley & Sons, Inc., New York, 1979, 564.

This book contains an edited version of the papers presented at the First International Conference on Environmental Forces on Engineering Structures, held at Imperial College, London, in July 1979. The topic of the conference was engineering structures subjected to natural environmental forces as the main design requirement. This includes wind, ocean, and earthquake effects on structures as well as such other topics as temperature effects, fatigue, vehicle loading, etc. A special session was devoted to the dynamic behavior of structures. Listed below are nine papers of interest to earthquake engineers. All the papers are abstracted or cited in this volume of the *AJEE.*

Environmental loadings on concrete cooling towers—types, likelihood, effects and consequences, Gould, P. L.—*A study of the measured and predicted behaviour of a 46-storey building,* Jeary, A. P. and Ellis, B. R.—*Earthquake floor response and fatigue of equipment in multi-storey structures,* Wilson, J. C.—*Determination of natural frequencies of the thin rotational shells by finite element method,* Delpak, R.—*Dynamics and stability of shells of revolution,* Collington, D. J. and Brebbia, C. A.—*Vibrations of spatial building structures,* Rosman, R.—*Interpolation-based methods for the efficient determination of the dynamic responses of linear structural systems,* Collings, A. G. and Saunders, L. R.—*Analytical computations of dynamic behaviour of pin jointed structures,* Ballio, G., Gobetti, A. and Zanon, P.—*Safety analysis for random elastic-plastic frames in the presence of second-order geometrical effects,* Casciati, F. and Faravelli, L.

● 1.2-29 Hedrick, J. K. and Paynter, H. M., eds., **Nonlinear system analysis and synthesis: Volume 1—Fundamental principles,** American Society of Mechanical Engineers, New York, 1978, 146.

This volume includes papers presented at a workshop during the 97th Winter Annual Meeting of the American Society of Mechanical Engineers (ASME) in New York on Dec. 5-10, 1976. The workshop was sponsored by the Automatic Control Div. (now the Dynamic Systems and Control Div.) of ASME. Those papers of interest to earthquake engineers are listed below; none of the papers are abstracted in this volume of the *AJEE.*

Chapter 1: Some fundamental principles of nonlinear systems, Meyer, A. U.—*Chapter 2: Stability of nonlinear systems,* Narendra, K. S.—*Chapter 3: Nonlinear system response: classical techniques for unforced response,* Paynter, H. M.—*Chapter 4: Nonlinear system response: quasilinearization methods,* Hedrick, J. K.

● 1.2-30 Miklowitz, J. and Achenbach, J. D., eds., **Modern problems in elastic wave propagation,** John Wiley & Sons, New York, 1978, 561.

This book contains the twenty-five papers presented at the International Union of Theoretical and Applied Mechanics Symposium on Modern Problems in Elastic Wave Propagation, held at Northwestern Univ. in Evanston, Illinois, Sept. 12-15, 1977. The speakers were drawn from the mechanics community, and from the fields of seismology, physics, acoustics, applied mathematics, and the areas of electrical devices and nondestructive testing. The papers give an up-to-date account of important research findings in the various disciplines concerned with elastic wave propagation. Among the topics covered are the influence of boundaries on waves in homogeneous, isotropic, linearly elastic media, and modern problems in such wave phenomena as diffraction, scattering, reflection, refraction, and dispersion, as well as the higher order effects of anistropy and inhomogeneity of the medium. Using analytical, numerical, and experimental methods, the papers offer approaches to the theoretical and practical applications of the subject.

● 1.2-31 **51st Annual Meeting, Eastern Section of the Seismological Society of America, Virginia Polytechnic Inst. and State Univ., Blacksburg, Virginia, Oct. 15-17, 1979, Program and Abstracts,** *Earthquake Notes,* **50,** 3, July-Sept. 1979, 3-46.

● 1.2-32 **ASCE Spring Convention and Exhibit, Apr. 2-6, 1979, Preprints,** American Society of Civil Engineers, New York, 1979.

The American Society of Civil Engineers held its 1979 Spring Convention and Exhibit in Boston from Apr. 2-6. Listed below are those preprints of interest to earthquake engineers. Some preprint titles are followed by an asterisk; this indicates that the preprint is a collection of papers. Preprint numbers follow the authors' names. None of the preprints are abstracted in this volume of the *AJEE* because of scheduling constraints.

Passive and active control of civil engineering structures, Yao, J. T. P. (3460)—*On constitutive models for analysis of concrete structures,* Chen, W.-F. and Ting, E. C. (3475)—*Highway corridor analysis in lifeline engineering,* Oppenheim, I. J. (3483)—*Seismic wave effects on water systems,* O'Rourke, M. J. et al. (3496)—*Design life simulation of a prestressed concrete reactor vessel,* Meyer, C. (3499)—*A testing facility for 3-D loading of structures,* Jirsa, J. O. and Breen, J. E. (3525)—*A finite element model for shear transfer in r/c,* Fardis, M. N. and Buyukozturk, O.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

(3547)—*An example of the application of reliability-based theory,* Gabrielsen, B. L. (3554)—*Evaluating old buildings for new earthquake criteria,* Freeman, S. A., Willsea, F. J. and Merovich, A. T. (3565)—*Massachusetts earthquake design requirements,* Luft, R. W. and Simpson, H. (3567)—*Analysis of rc shells for time-dependent effects,* Kabir, A. F. and Scordelis, A. C. (3575)—*Design of large scale tuned mass dampers,* Petersen, N. R. (3578)—*Rough cracks in reinforced concrete,* Bazant, Z. P. and Gambarova, P. (3579)—*On seismic analysis and design of underground lifelines,* Weidlinger, P. and Nelson, I. (3586)—*Direct models of precast concrete large panel buildings,* Harris, H. G. and Muskivitch, J. C. (3587)—*Inelastic aseismic design of r.c. wall structures,* Fintel, M. and Ghosh, S. K. (3589)—*Long span suspension bridges: history and performance* * (3590)—*Seismic response of large panel precast concrete shear walls,* Becker, J. M., Llorent, C. and Mueller, P. (3593)—*Civil engineering and nuclear power* * (3594, 3595, 3596)—*Plastic analysis of civil engineering structural systems: state-of-the-art* * (3599)—*Reliability analysis and geotechnical engineering* * (3600)—*New techniques in structural analysis by computer* * (3601)—*Engineering geology in New England* * (3602)—*U.S./British developments in offshore platforms* * (3603)—*Soil dynamics in the marine environment* * (3604).

● **1.2-33 ASCE Fall Convention, Oct. 23-25, 1979, Preprints,** American Society of Civil Engineers, New York, 1979.

The ASCE Fall Convention was held from Oct. 23-25, 1979, in Atlanta. Eleven preprints relevant to earthquake engineering are listed below. An asterisk after a preprint title indicates that the preprint is a collection of papers; all other preprints are individual papers. Preprint numbers appear in parentheses following the authors' names. Because of scheduling constraints, none of these preprints are abstracted in this volume of the *AJEE.*

Influence of end restraint on column stability, Chen, W. F. (3608)—*Vertical vibration analysis of suspension bridges,* Abdel-Ghaffar, A. M. (3627)—*Simulation of earthquake motion by contained explosions,* Schwer, L. E., Bruce, J. R. and Lindberg, H. E. (3649)—*Seismic behavior of structural subassemblages,* Popov, E. P. (3670)—*Analysis and design of reinforced concrete walls,* Breen, J. E. et al. (3681)—*Seismic design criteria, stated and implied,* Zacher, E. G. (3715)—*Simplified seismic stability analysis: program documentation,* Grigg, R. F. and Lo, R. C. Y. (3746)—*Connections between steel beams and concrete walls,* Roeder, C. W. and Hawkins, N. M. (3779)—*Centrifugal modeling of geotechnical problems* * (3786)—*Storage of spent nuclear fuel* * (3791-3792)—*Geophysical methods in geotechnical engineering* * (3794).

● **1.2-34** Szoke, D., **RILEM International Symposium on In Situ Testing of Concrete Structures** (Colloque RILEM international essais in situ des structures en beton, in French and English), *Matériaux et Constructions,* **12,** *70,* July-Aug. 1979, 307-319.

The International Union of Testing and Research Labs. for Materials and Structures (RILEM) sponsored an international symposium in Budapest on Sept. 12-15, 1977, on the topic of in-situ testing of concrete structures. The symposium was jointly organized by the RILEM Technical Committee 20-TBS and the collective members of the Hungarian section of RILEM. More than 200 participants representing 30 countries attended the meeting.

● **1.2-35** Lew, H. S., ed., **Wind and seismic effects,** *NBS Special Publication 523,* Proceedings of the Ninth Joint Panel Conference of the U.S.-Japan Cooperative Program in Natural Resources, Center for Building Technology, U.S. National Bureau of Standards, Washington, D.C., 1978, 518.

The Ninth Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects was held in Tokyo on May 24-27, 1977. The proceedings contain the program, the formal resolutions, and the technical papers. The subjects covered include: (1) characteristics of strong winds; (2) wind loads on structures and design criteria; (3) earthquake prediction; (4) earthquake ground motions and soil failures; (5) seismic loads on structures and design criteria; (6) design of special structures; (7) earthquake hazard reduction program; and (8) quantitative evaluation of damage caused by winds and earthquakes. Because of scheduling constraints, none of the papers are abstracted in this volume of the *AJEE.*

● **1.2-36 Analysis of Actual Fault Zones in Bedrock, Proceedings of Conference VIII,** *Open-File Report 79-1239,* convened under auspices of National Earthquake Hazards Reduction Program, Apr. 1-5, 1979, Palm Springs, California, Office of Earthquake Studies, U.S. Geological Survey, Menlo Park, California, 1979, 595.

● **1.2-37 Central American Conference on Earthquake Engineering: Volume 1** (in English or Spanish), Envo Publishing Co., Inc., Lehigh Valley, Pennsylvania, 1978, 1 vol.

The conference, held in San Salvador from Jan. 9-12, 1978, was sponsored by the Univ. Centroamericana Jose Simeon Canas, the Ministry of Public Works of El Salvador, and Lehigh Univ. The purpose of the conference was to provide up-to-date information needed to assist people living in the highly seismic region of Central America. Eight major subjects are covered in the proceedings: seismic risk analysis, earthquake prediction, soil-structure interaction, structural response, seismic-resistant design, low-cost construction, rehabilitation, and building codes. More than 100 papers were presented at the conference. Volume 1 of the proceedings contains the technical papers.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

It is planned that state-of-the-art reports and discussions will be published in Volume 2 in the future. None of the papers from Volume 1 are abstracted in this volume of the *AJEE.*

● 1.2-38 Ellyin, F. and Neale, K. W., eds., **CANCAM 79, Seventh Canadian Congress of Applied Mechanics** (in English or French), Seventh Canadian Congress of Applied Mechanics, Univ. de Sherbrooke, Sherbrooke, Quebec, 1979, 2 vols.

The proceedings contain the abstracts of all contributed original research and technical papers and the texts of the five invited lectures presented at the Seventh Canadian Congress of Applied Mechanics. The congress was held at the Univ. de Sherbrooke, Sherbrooke, Quebec, from May 27 to June 1, 1979. The abstracts have been grouped as follows: Solid Mechanics and Dynamics in Volume 1 and Fluid Mechanics, Thermodynamics, and Heat Transfer; Biomechanics; and Applied Mathematics and Computer Techniques in Volume 2. In Volume 1, sections are included on random, nonlinear, and beam vibrations; structural dynamics; system identification; general, experimental, and plate and shell dynamics; and seismic analysis. None of the abstracts are contained in this volume of the *AJEE.*

● 1.2-39 Stephens, H. S. and Knight, S. M., eds., **International Conference on the Behaviour of Off-Shore Structures, Proceedings of the Second (BOSS'79)**, BHRA Fluid Engineering, Bedford, United Kingdom, 1979, 2 vols.

The conference was held at the Imperial College in London from Aug. 28 to 31, 1979, and was sponsored by the Norwegian Inst. of Technology, Delft Univ. of Technology, the Massachusetts Inst. of Technology, and the Univ. of London. Volume 1 contains 26 of the invited papers and 13 of the contributions as well as the three general lectures. Volume 2 contains 30 of the invited papers and nine of the contributions. The remaining papers and contributions and an edited record of the discussions will appear in Volume 3. None of the papers are abstracted in this volume of the *AJEE.*

● 1.2-40 **Engineering application of the finite element method**, Papers presented at International Conference, held May 9-11, 1979, A.S. Computas, Hovik, Norway, 1979, 2 vols.

The conference was held at the Veritas Center in Hovik, Norway. Contained in the proceedings are 27 papers and three short presentations. The conference was divided into the following sessions: application of the finite element method in the analysis of dynamics, static, and field problems; fluid-structure interaction; nonlinear analysis and fracture mechanics; prospects for structural analysis in the next decade—problems, solution algorithms, and computer programs. None of the papers are abstracted in this volume of the *AJEE.*

● 1.2-41 Bathe, K.-J., ed., **Nonlinear finite element analysis and ADINA**, *Report 82448-9,* Proceedings of the Second ADINA Conference, held Aug. 1-3, 1979, at the Massachusetts Inst. of Technology, Acoustics and Vibration Lab., Massachusetts Inst. of Technology, Cambridge, 1979, 775.

● 1.2-42 **Urban Design and Seismic Safety: US/Japan Joint Research Seminar, May 22-25, 1979, Tokyo**, Dept. of Architecture, Univ. of Hawaii, and City Planning Committee of Architectural Inst. of Japan, Manoa and Tokyo, 1979, 1 vol.

● 1.2-43 **International Brick Masonry Conference, 5th, 1979, Preprints of papers to be delivered**, held at Washington, D.C., Oct. 5-10, 1979, Brick Inst. of America, McLean, Virginia, 1979, 1 vol.

The conference was divided into the following sessions: manufacture of brick and energy savings, properties and behavior of materials, architectural design and decisions, properties and behavior of elements and whole structures, structural design and detailing, energy conservation and special systems, economic and social considerations. None of the preprints are abstracted in this volume of the *AJEE.*

● 1.2-44 Wittke, W., ed., **Numerical methods in geomechanics**, Proceedings of the Third International Conference on Numerical Methods in Geomechanics, Aachen, Apr. 2-6, 1979, A. A. Balkema, Rotterdam, 1979, 3 vols.

The conference was sponsored by the International Committee on Numerical Methods in Geomechanics and the Inst. for Foundation Engineering, Soil Mechanics, Rock Mechanics and Water Ways Construction, Univ. of Aachen. Volume 1 contains papers in the areas of theoretical developments, flow and consolidation, and constitutive laws; Volume 2, rock behavior, underground openings, embankments and slopes, and dynamics; and Volume 3, soil-structure interaction (foundations) and soil-structure interaction (retaining structures). Publication of a fourth volume is planned. None of the papers are abstracted in this volume of the *AJEE.*

● 1.2-45 **International Seminar on Probabilistic and Extreme Load Design of Nuclear Plant Facilities**, Proceedings, held Aug. 22-24, 1977, in San Francisco, American Society of Civil Engineers, New York, 1979, 2 vols., 446.

● 1.2-46 **Seminar on the Protection of Monuments in Seismic Areas** (Seminario sobre Proteccion de Monumentos en Areas Sismicas, in Spanish or English), Guatemala Consejo Nacional para la Proteccion de la Antigua, Guatemala, 1979, 13 vols. in 1.

● *See **Preface**, page v, for availability of publications marked with dot.*

The seminar was held in Antigua, Guatemala, on Nov. 4-11, 1979. A supplemental catalog prepared by the International Committee Seism of the International Council on Monuments and Sites was distributed at the seminar. See Abstract No. 9.2-13 for a bibliographic citation for the catalog.

● 1.2-47 **Workshop on Earthquake Resistance of Highway Bridges,** *ATC 61-1,* Proceedings, held on Jan. 29-31, 1979 in San Diego, California, and conducted by Applied Technology Council, Applied Technology Council, Palo Alto, California, 1979, 625.

● 1.2-48 **Contributions from the Instituto de Ingenieria, Universidad Nacional de Autonoma de Mexico at the Central American Conference on Earthquake Engineering, held in San Salvador, El Salvador, January 1978** (Contribuciones del Instituto de Ingenieria, UNAM a la Conferencia Centroamericana de Ingenieria Sismica celebrada en San Salvador, El Salvador en Enero de 1978, in Spanish), *Ingenieria Sismica, 20,* Jan.-Apr. 1978, 1-46.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

2. Selected Topics in Seismology

2.1 Seismic Geology

● 2.1-1 Murdock, J. N., **A tectonic interpretation of earthquake focal mechanisms and hypocenters in Ridge Basin, southern California,** *Bulletin of the Seismological Society of America,* **69**, *2*, Apr. 1979, 417–425.

Ridge Basin is in the territory of the current uplift in southern California. The basin is bounded by the San Gabriel and San Andreas faults. During a seismic experiment conducted in 1972 to 1973, 42 small earthquakes were located in the region of the basin. Approximately one-third of the epicenters lie near the San Gabriel fault for a distance of more than 10 km. The composite focal mechanism plot of the epicenters does not show uniquely defined nodes. However, the data permit a solution that agrees with known parameters of the San Gabriel fault; namely, a vertical fault that strikes northwest, with a right-lateral strike-slip displacement. A composite fault-plane solution for most of the remaining events in the basin gives two well-constrained nodes; one dips southeast nearly parallel with the dip of the hypocenter zone and, therefore, is assumed to be the fault plane. It strikes northeast almost parallel to the basin hinge line of late Pliocene-early Pleistocene age, and the solution indicates reverse right-oblique displacement. The history of the basin suggests that reverse faulting should be expected to accompany subsidence, and subsidence is indeed suggested in the northwest part of the basin where the valleys appear inundated with sediments. Whereas the dip-slip component of faulting corresponds to basin formation, the strike-slip component of the right-oblique movement may relate to the tectonic process that is locking the San Andreas fault. Since the Pliocene was a time of formation of the basin, and the mid- and late Pleistocene mainly was a time of folding and erosion of lower Pleistocene and older rocks, the proposed model seems more analogous to the Pliocene tectonic cycle than to the Pleistocene cycle. Both Pyramid and Castaic dams are situated in the basin. Their location with respect to the faults of the earthquakes is not resolved.

● 2.1-2 Eisbacher, G. H., **First-order regionalization of landslide characteristics in the Canadian Cordillera,** *Geoscience Canada,* **6**, *2*, June 1979, 69–79.

Landslide modes in the Canadian Cordillera are divided into eight zones according to the dominance of specific types of failure and mass transport. The Coast-Insular Zone is dominated by rock falls, rock avalanches, and debris and earth flows; the St. Elias Zone by rock slumps and debris flows; the Plateau Zone by earth flows and rock slumps; the Skeena Zone by rock slumps; the Yukon-Selwyn Basin Zone by rock slumps; the Cassiar-Columbia Zone by deep-seated slope-sagging and gravitational spreading; the Eastern Carbonate Zone by rock avalanches and debris flows; the Foothills Zone by soft rock slumps and earth flows. The large number of landslides in the Canadian Cordillera is related to the complex interaction of local geology and to such regional factors as relief, intensity of precipitation, and seismicity. The landslide hazard deserves special attention in the recreational hinterland of Vancouver and Calgary.

● 2.1-3 Savage, J. C. and Prescott, W. H., **Geodimeter measurements of strain during the southern California uplift,** *Journal of Geophysical Research,* **84**, *B1*, Jan. 10, 1979, 171–177.

A review of geodimeter measurements made along the "big-bend" section of the San Andreas fault in southern California indicates no significant increment in strain during the period of major uplift (late 1959 to mid-1963). Specifically, no evidence of an increment in compressional strain normal to the San Andreas fault at the time of the uplift was found. Geodolite measurements at four networks along the big bend independently indicate that the strain rate during the 1974-1977 episode of subsidence was

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

essentially a uniaxial north-south compression at the rate of about 1/3 μstrain/yr. Whether the 1974-1977 rate is significantly different from earlier rates determined by triangulation is not clear owing to a rather large variability in the earlier determinations.

● **2.1-4** Sbar, M. L. et al., **Stress pattern near the San Andreas fault, Palmdale, California, from near-surface in situ measurements,** *Journal of Geophysical Research,* **84,** *B1,* Jan. 10, 1979, 156-164.

Twenty-nine in-situ doorstopper strain relaxation measurements were made from eight sites spaced on a 35 km transect extending from the foothills of the San Gabriel Mountains, across the San Andreas fault, and into the western Mojave Desert southeast of Palmdale, California. This was a pilot study to test whether such measurements can detect the regional stress field and any of its modifications in a tectonically complex area. Strain was measured by overcoring strain gauge rosettes which had been bonded to the flattened bottom of a shallow borehole. Stress measurements were able to be repeated at each site. NNE-trending maximum compressive stress (σ_1) was found at the sites farthest from the fault. This orientation is parallel to the σ_1 inferred from fault plane solutions of major southern California earthquakes and compares favorably with deep hydrofracture stress measurements made near the sites used in this study. Nearer the San Andreas fault, the orientation of σ_1 was approximately east-west north of the fault, and northwest-southeast to north-south south of the fault. That measurements were able to be repeated at a site and that the measurements of this study compared favorably with Tullis' (1977) near-surface stress measurements suggest that the stress field orientation present at a site was reliably determined in this study. Using the available data, it was not possible to distinguish the stress caused by residual or topographic effects from tectonically applied stress nor to account for modification of the stress field by decoupling across fractures.

● **2.1-5** Lisowski, M. and Savage, J. C., **Strain accumulation from 1964 to 1977 near the epicentral zone of the 1976-1977 earthquake swarm southeast of Palmdale, California,** *Bulletin of the Seismological Society of America,* **69,** *3,* June 1979, 751-756.

Strain accumulation in a 5 by 7 km, 10-station network that spans the San Andreas fault 20 km southeast of Palmdale, California, has been calculated by comparing a 1964 triangulation survey with a 1977 trilateration survey. The network is located within the epicentral area of the anomalous 1976-1977 earthquake activity reported by McNally and Kanamori. The comparison indicates shear strain accumulation of $\gamma_1 = 10.8 \pm 1.8$ ppm and $\gamma_2 = 5.1 \pm 1.8$ ppm for the 13-year period, where $\gamma_1 = \epsilon_{11} - \epsilon_{22}$ and $\gamma_2 = 2\epsilon_{12}$ and ϵ_{ij} are the tensor strain components in a coordinate system with the 1-axis directed to the east and the 2-axis to the north. A simple dislocation model of the 1971 San Fernando earthquake predicts coseismic shear strains $\gamma_1 = 2.8$ ppm and $\gamma_2 = 1.7$ ppm in the area of the network. The 1964-1977 shear strains corrected for the San Fernando earthquake and translated into yearly rates are $\gamma_1 = 0.60 \pm 0.14$ ppm/yr and $\gamma_2 = 0.26 \pm 0.14$ ppm/yr with the direction of maximum extension N75°E ± 6°. Shear strain rates $\gamma_1 = 0.38 \pm 0.06$ ppm/yr and $\gamma_2 = 0.20 \pm 0.06$ ppm/yr with the direction of maximum extension N80°E ± 7° in the period August 1971 to July 1977 have been reported for the Palmdale network located 30 km northeast along the San Andreas fault. Corrected for the effects of the 1971 San Fernando earthquake, the 1964-1977 shear strain rates for the network near the 1976-1977 earthquake swarm are not significantly higher than, and agree in orientation with, those for the Palmdale network in the 1971-1977 period. Thus, no strain event of magnitude greater than a few parts per million has been associated with the anomalous earthquake activity.

2.1-6 Keys, W. S. et al., **In-situ stress measurements near the San Andreas fault in central California,** *Journal of Geophysical Research,* 84, *B4,* Apr. 10, 1979, 1583-1591.

A series of stress measurements using hydraulic fracturing techniques were made in five holes drilled into shale along a line normal to, and 3-18 km from, the trace of the San Andreas fault. In all the holes, except the one farthest from the fault, the least principal stresses were found to be approximately equal to the weight of the overburden. The drilling as well as the variation in breakdown pressures suggested a somewhat viscoelastic material. The data further suggested that the shale does not retain the regional tectonic stresses. The dip of most of the hydraulic fractures was greater than 69°. Televiewer logs showed that the natural fractures have a consistent dip of 58° principally to the west-southwest. Although widely scattered, the orientations of the total set of natural and hydraulic fractures suggest that the direction of maximum principal stress is north-south. The strike of the San Andreas fault is N45°W, which falls within the limits of the relationship of stress distribution and fault trace predicted on the basis of the Mohr-Coulomb theory for strike-slip faults. It is suggested that more competent rocks would be better suited to a study of the relationship of tectonic stresses to the San Andreas fault.

● **2.1-7** Lambert, A. and Vanicek, P., **Contemporary crustal movements in Canada,** *Canadian Journal of Earth Sciences,* **16,** *3 (Part 2),* Mar. 1979, 647-668.

The known patterns and causes of contemporary aseismic movements of the crust in Canada are reviewed. Modern and paleo-water-level data and geodetic releveling data are being used to delineate the regional pattern of

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

vertical movements, but equivalent data on regional horizontal movements are not yet available. The first steps are being taken to relate the emerging regional pattern of vertical movement in Canada to the interactions on the western margin of the North American plate and to the spatial variations in seismicity, gravity field, and crustal stress in the plate interior. Viscoelastic modeling of the response of the earth to surface loads and laboratory-based results on possible nonlinear rheologies in the mantle have provided a useful theoretical framework for comparing new data on ice-sheet histories with paleo-water-level results. Local-scale crustal deformations are being monitored by triangulation, leveling, and gravity networks, as well as by tiltmeters, strainmeters, and well-water-level meters. The interpretation of the local deformation data has been facilitated by modeling of the response of inhomogeneous-elastic and porous-elastic media. The level of research activity on local aseismic movements in different areas of Canada corresponds to the seismotectonic significance of the areas.

2.1-8 Holzer, T. L., Davis, S. N. and Lofgren, B. E., **Faulting caused by groundwater extraction in southcentral Arizona,** *Journal of Geophysical Research,* **84,** *B2,* Feb. 10, 1979, 603–612.

Modern surface faulting, 4.8 km southeast of Picacho, Arizona, has created a scarp ranging from 0.2 to 0.6 m high and approximately 15 km long. The scarp, which has been steadily increasing in height since it began to form in 1961, occurs along the eastern margin of the Eloy-Picacho subsidence bowl where more than 2.9 m of land subsidence, caused by declines of groundwater levels, occurred from 1934 to 1977. It is concluded that faulting is related to groundwater withdrawal. First, the scarp is restricted to an area underlain by alluvium in which groundwater levels have declined. Second, faulting postdates the beginning of water-level declines and associated land subsidence. Third, observed vertical displacements associated with faulting are compatible with results from a model of subsurface faulting in which rupture does not extend beneath the zone affected by stresses related to declines of water levels. The model is based on elastic dislocation theory. Fourth, analysis of levelings of bench marks unaffected by man-induced subsidence indicates minor regional crustal movements that do not appear to be compatible with the magnitude of fault offset.

2.1-9 Eisbacher, G. H., **Cliff collapse and rock avalanches (sturzstroms) in the Mackenzie Mountains, northwestern Canada,** *Canadian Geotechnical Journal,* **16,** 2, May 1979, 309–334.

Cliff collapse and resulting rock avalanches or sturzstroms have occurred widely in the carbonate formations of the Mackenzie Mountains in northwestern Canada. Some of the rock slides are close to a Holocene fault scarp and may be a result of past earthquake activity. The Mackenzies are located within an intraplate seismic zone; presently monitored seismic activity may not indicate the maximum level of ground motion that caused the failure of large rock slopes during the last 10,000 years. At several localities, at least two generations of slide material can be recognized. All major sturzstroms originated by failure above inclined bedding plane surfaces, ranging in dip from 13-40°. Two stages must be considered in the mechanical analysis of dry sturzstroms: failure and streaming. Failure can occur by either sliding (static friction of about tan 30°) or roller bearing and internal collapse (kinetic friction as low as tan 13°). Streaming is initiated by momentum transfer from the back of a collapsing cliff to its frontal disintegrating portion and facilitated by dispersion of large blocks in finer interstitial material. Prediction of reach or excessive travel distance of dry sturzstroms is not simple because the effects of slide mass, fall height, topographic constraints, and lithology must be considered. The best method of predicting reach in a potential sturzstrom situation is comparison with documented sturzstroms in similar geologic, climatic, and topographic settings.

● **2.1-10** Bennett, J. H., **Fault creep measurement,** *California Geology,* 32, *5,* May 1979, 98–105.

The California Div. of Mines and Geology has used an electronic distance measuring system since 1974, principally for measurement of fault creep. Some of the purposes for which these surveys may be conducted and typical results that can be achieved with this instrumentation are discussed.

● **2.1-11** Harpster, R. E., Biggar, N. E. and Anttonen, G. J., **Methods of investigating fault activity in the western Sierran foothills, California,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1144–1150.

This paper presents methods developed to assess fault activity and seismic hazards in the western Sierran foothills. The initial site of the investigations was the Cleveland Hill area near Oroville, California, where 25 trenches were sited at five exploration localities across surface faulting features associated with the Oroville earthquake of 1975. On the basis of findings at Cleveland Hill, the study was expanded to include approximately 30 additional exploration localities elsewhere in the foothills, where more than 100 trenches were excavated across known and potential faults. The techniques used represented a chronological continuum in which the initial methods used during the Cleveland Hill study were refined as data from successive exploration localities were assessed. Additional data pertinent to

● *See **Preface,** page v, for availability of publications marked with dot.*

the development of the methods were derived from concurrent supporting studies that were necessary for an understanding of the geologic environment of the western Sierran foothills.

2.1-12 Thatcher, W., **Horizontal crustal deformation from historic geodetic measurements in southern California,** *Journal of Geophysical Research,* **84,** *B5,* May 10, 1979, 2351-2370.

In this study, data from horizontal control surveys are used to determine the regional deformation pattern across the southern San Andreas fault system and the history of movements since ~1930. The interseismic straining is spread over a wide zone, with no sharp concentration across major faults and with significant deformation extending out to distances approximately 100 km from the San Andreas fault. The maximum right-lateral shear straining parallels the trends of the northwest striking faults of the region and tensor rates of from 0.1 to 0.2 X 10^{-6}/yr are observed. A slight decrease in strain rate away from the San Andreas is indicated by the data, but shallow seismic slip on this fault alone is incapable of releasing all accumulated strains. The substantial residual deformation then must be accommodated by other means, and the range of possibilities includes: (1) permanent inelastic deformation over a broad region, (2) massive pre- and/or post-seismic slippage on the San Andreas beneath the brittle seismic zone, and (3) earthquake faulting on several subparallel active strands of the San Andreas system. Although available data are insufficient to exclude any of these possibilities, the diffuse seismicity and numerous active faults of the region suggest the third mechanism is the predominant one. Aseismic fluctuations in the rate of deformation have been inferred during the 1959-1974 southern California uplift, and long-lived, wide-ranging postseismic effects have been observed following several major earthquakes and are particularly well-documented for the 1940 El Centro shock (M = 7.1). Such effects are large and unexpected, complicate determination of the pattern of secular deformation, and are difficult to separate from suspected earthquake precursors. Determination of the rate of relative plate motion across southern California is made difficult by both the great breadth of the zone of secular straining and the observed irregularities in deformation rate.

● 2.1-13 Zoback, M. D. and Roller, J. C., **Magnitude of shear stress on the San Andreas fault: implications of a stress measurement profile at shallow depth,** *Science,* **206,** *4417,* Oct. 26, 1979, 445-447.

A profile of measurements of shear stress perpendicular to the San Andreas fault near Palmdale, California, shows a marked increase in stress with distance from the fault. The pattern suggests that shear stress on the fault increases slowly with depth and reaches a value on the order of the average stress released during earthquakes. This result has important implications for both long- and short-term prediction of large earthquakes.

2.1-14 Davies, J. N. and House, L., **Aleutian subduction zone seismicity, volcano-trench separation, and their relation to great thrust-type earthquakes,** *Journal of Geophysical Research,* **84,** *B9,* Aug. 10, 1979, 4583-4591.

A seismic network has been operating in the Shumagin Islands and the adjacent Alaska Peninsula since July 1973. Hypocentral cross sections based on the first 4 yr of data from this network show a well-defined Benioff zone that is about 10 km thick and extends to a depth of about 180 km. Focal mechanism and strong-motion accelerograph data for an m_b = 6.0 earthquake at a depth of 40 km indicate a slip plane subparallel to the Benioff zone. This event is interpreted as being directly caused by the underthrusting of the Pacific lithosphere beneath the Shumagin Islands. Comparison of the Shumagin hypocentral cross section with cross sections from other regions of the Aleutian arc shows that at depths greater than 40 km (1) the Benioff zones are nearly congruent, and (2) their positions relative to the volcano line are nearly the same along the entire length of the arc. This comparison also reveals that the eastward widening of the volcano-trench separation occurs predominantly in the shallowly dipping extension of the Benioff zone from its position at a depth of 40 km to where it outcrops near the trench; this extension is herein termed the main thrust zone. Rupture zones of the great earthquakes of 1964, 1965, and possibly 1938 along the Aleutian arc are confined to the main thrust zone. This observation and the very low level of seismic activity at the present time in the main thrust zone compared to that in the Benioff zone below a depth of 40 km suggest that seismic activity in the main thrust zone is dominated by great earthquakes and their aftershocks, followed by long intervals of quiescence. The Benioff zone below 40 km depth shows more continual seismic activity. For the Aleutian arc, there exists a weak correlation between the width of the main thrust zone and the rupture length and magnitude (Mw) of great earthquakes.

2.1-15 Kumar, M., **Significance of β error in the assessment of crustal movements,** *Surveying and Mapping,* **XXXIX,** *2,* June 1979, 133-136.

Statistical inferences from repeated surveys conducted to investigate recent crustal movements are discussed. The recommended testing brings out the significance and importance of a β error in such analyses. A simulated example is discussed to show that although changes in position vectors of stations in a fault zone may satisfy testing of an α error at some pre-assigned significance level, a more meaningful inference, with additional confidence, can only be drawn from an assigned power 1-β and from computing the rejection criteria associated with the assigned power.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

2.1-16 Russ, D. P., **Late Holocene faulting and earthquake recurrence in the Reelfoot Lake area, northwestern Tennessee,** *Geological Society of America Bulletin, Part I,* **90,** *11,* Nov. 1979, 1013–1018.

Faults, folds, and sand dikes have been identified in late Holocene sediments exposed in an exploratory trench excavated across Reelfoot scarp in northwestern Tennessee. In excess of 3 m of vertical displacement believed to be of deep-seated origin occurs across a 0.5-m-wide zone of east-dipping normal faults near the scarp base. The zone includes the only faults of probable tectonic origin known to cut Holocene sediments in the upper Mississippi embayment. Stratigraphic and geomorphic relationships suggest, however, that little (<0.5 m) or no near-surface fault movement occurred across the zone during the high-magnitude New Madrid earthquakes of 1811–1812. Numerous faults having only minor displacements were mapped elsewhere in the trench. Geologic relationships between the faults and sand dikes indicate that the faults were formed contemporaneously with the dikes during high-magnitude earthquakes. Crosscutting geologic features and local geomorphic history suggest that at least two periods of faulting predate sediments deposited before 1800. Thus historical data and the sediments in the trench record a history of three earthquakes near the trench site strong enough to liquefy sediments and generate faulting. Carbon-14 dates obtained on fresh-water shells indicate that the trench sediments have a maximum age of about 2000 radiocarbon yr. A recurrence interval of approximately 600 yr or less is suggested for large earthquakes in the New Madrid area.

2.1-17 Zoback, M. D., **Recurrent faulting in the vicinity of Reelfoot Lake, northwestern Tennessee,** *Geological Society of America Bulletin, Part I,* **90,** *11,* Nov. 1979, 1019–1024.

Reelfoot Lake in northwestern Tennessee was the site of considerable ground motion at the time of the 1811–1812 New Madrid earthquakes. Thirty-two km of conventional seismic-reflection profiling in the vicinity of the lake has revealed the existence of many faults. Most significant are two high-angle faults with 50 to 60 m of vertical offset at the contact of the Late Cretaceous embayment sediments and Paleozoic bedrock. One fault is associated with the scarp on the western edge of the Reelfoot Lake and the other fault with a major northeast-trending lineament that passes through the town of Ridgely, Tennessee, and near the southeast edge of Reelfoot Lake. The nature of the observed vertical offsets suggests recurrent motion on faults of Late Cretaceous, or older, age.

● **2.1-18** Seno, T., **Intraplate seismicity in Tohoku and Hokkaido and large interplate earthquakes: a possibility of a large interplate earthquake off the southern Sanriku coast, northern Japan,** *Journal of Physics of the Earth,* **27,** *1,* 1979, 21–51.

Historic seismicity data recorded since 1850 for Tohoku and Hokkaido in northern Japan show a spatial and temporal correlation between intraplate seismicity in the land area and the occurrence of large interplate earthquakes along the Japan and Kuril trenches. In the continental lithosphere adjacent landward to the rupture zones of recent large interplate earthquakes, almost all the earthquakes of magnitude 6.0 and greater occurred within 60 years (50 years before to 10 years after) the occurrence of the large interplate events. A simple statistical test shows that this correlation is significant at a 99.5% confidence level. During the last 20 years, a group of intraplate earthquakes have occurred in the mid-Tohoku area but no large interplate earthquakes have occurred seaward of the intraplate earthquake epicentral locations. This suggests the possibility that a large interplate event will occur off the southern Sanriku coast in the near future. Other geophysical data, i.e., historic and recent seismicity data and crustal deformation measurements, provide support for such a possibility. Source parameters estimated for this expected event conform to those of recent large interplate events along the Japan and Kuril trenches. The correlation between intraplate seismicity and large interplate earthquakes is used as a criterion for forecasting the land area of high seismic risk for intraplate events and for forecasting the rupture zone of an impending large interplate earthquake. This procedure may be of significance in developing instrumentation to detect various types of precursory phenomena associated with intraplate and/or interplate earthquakes.

● **2.1-19** Swanson, D. A. et al., **Chronological narrative of the 1969–71 Mauna Ulu eruption of Kilauea Volcano, Hawaii,** *U.S. Geological Survey Professional Paper 1056,* U.S. Government Printing Office, Washington, D.C., 1979, 55.

The 1969–1971 Mauna Ulu eruption on the upper east rift zone of Kilauea Volcano lasted from May 24, 1969, to Oct. 15, 1971. It was the longest and most voluminous flank eruption at Kilauea during historic time. The eruption illustrated well the integrated system that constitutes a volcano in Hawaii; for example, seismicity and ground deformation in Kilauea's summit region were systematically correlated with the eruptive behavior of Mauna Ulu 8 to 9 km away. These correlations demonstrated that magma continually entered a shallow reservoir of complex nature beneath Kilauea's summit at a rate of about 0.3×10^6 m^3/day. Ground deformation and seismic studies showed that the reservoir inflated when the rate of magma supply exceeded outflow, deflated when outflow exceeded supply, and remained in equilibrium when rates of supply and outflow were balanced.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

Observations of the eruption provided a wealth of information about the development of parasitic shield volcanoes, the nature of the gas-piston process, the formation of lava tubes and their importance in carrying lava long distances, and a host of other processes not generally available for study during shorter eruptions. This report describes all stages of the eruption in detail. Numerous photographs, maps, diagrams, and tables are included; among them is a diagram summarizing the tilt, daily number of earthquakes, and the important volcanic events that occurred during the period.

● 2.1-20 DuBois, S. M., **The origin of surface lineaments in Nemaha County, Kansas,** *NUREG/CR-0321,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Aug. 1978, 49.

Linear and curvilinear features detected on remote sensing imagery were correlated to drainage patterns in Nemaha County, Kansas. The influence of the Nemaha Ridge on present drainage networks appears significant. The Humboldt fault was shown to breach the surface in the Fourmile Creek drainage basin near Bern, Kansas, offsetting Permian and Pennsylvanian beds by 54 to 74 m. Steep aeromagnetic and gravity gradients are superimposed over the trace of the Humboldt fault zone and it is likely that they are related to the fault zone. The geophysical data suggest a complexly fractured basement surface. Several of the linear trends apparent on the aeromagnetic map coincide with present drainage trends. Available subsurface well information was used to generate a modified interpretation of the Precambrian surface configuration compatible with geophysical and surface observations. The underlying structure, especially on the west side of the Humboldt fault zone where basement rocks are relatively shallow, is believed to exert considerable control over present drainage patterns. A lineament formed by two streams near Baileyville, Kansas, suggests recent movement in glacial deposits.

● 2.1-21 Burchett, R. R. and Maroney, D. G., **Regional tectonics and seismicity of eastern Nebraska: annual report, June 1977-May 1978,** *NUREG/CR-0876,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1979, 163.

This annual report presents and interprets the information obtained by the Nebraska Geological Survey on the geology, structure, tectonics, and seismicity of eastern Nebraska, with emphasis on the vicinity of the Humboldt fault zone in western Richardson and eastern Pawnee counties. The scope of the studies is summarized as follows. (1) Rock outcrops in western Richardson and eastern Pawnee counties were reexamined and reevaluated, and 64 test holes were drilled to determine the altitude of the upper surface of the Tarkio Limestone of Pennsylvanian age. (2) The possible relationship of earthquakes in eastern Nebraska to Pleistocene glaciation was evaluated. (3) Three new seismograph installations were established in southeastern Nebraska. (4) Gravity surveys of western Richardson and eastern Pawnee counties were extended to the northern end of the Humboldt fault zone and were evaluated. (5) Ground magnetic surveys in western Richardson and eastern Pawnee counties were made and evaluated. (6) Gravity and ground magnetic surveys of the Elk Creek anomaly were made and evaluated. Discussions of the results of these studies constitute the remainder of this report.

● 2.1-22 Stearns, R. G., **Recent vertical movement of the land surface in the Lake County uplift and Reelfoot Lake basin areas, Tennessee, Missouri and Kentucky,** *NUREG/CR-0874,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1979, 37.

Tiptonville Dome, an established tectonic uplift, is one in a 20-mi series of en echelon topographic highs, most of which are uplifts. Because these features were too high to have been flooded during the largest historic floods, they became temporary islands. From Lewis Prairie, at New Madrid, Missouri, five such topographically high areas extend southward across the Mississippi River to Ridgely, Tennessee. Although separated now by modern river erosion, they were nearly continuous in 1811. Contour trends reveal a squarish topographic bulge west of the "flood islands," the western corner of which is near Portageville, Missouri. This bulge may have been uplifted with the islands, although not to the same extent. This bulge and the topographic highs compose the Lake County uplift. Ridgely Ridge and Tiptonville Dome in Tennessee correlate with positive gravity anomalies, and small earthquakes are concentrated beneath or near them. Thus these topographic features may be surface manifestations of deep-seated tectonic movements that continue today.

● 2.1-23 LaForge, R. and Engdahl, E. R., **Tectonic implications of seismicity in the Adak Canyon region, central Aleutians,** *Bulletin of the Seismological Society of America,* 69, 5, Oct. 1979, 1515-1532.

Adak local-network and teleseismically recorded data are used to describe shallow seismicity and tectonics in the Adak Canyon region of the central Aleutians. An examination of the locations and focal mechanisms of earthquakes up to 50 km in depth, occurring between July 1974 and Dec. 1976, permits the subdivision of this activity into a northward dipping zone of thrusting and an overlying wedge-shaped zone of normal faulting. The thrust zone is characterized by an upper part which has been the source for all large thrust earthquakes occurring in the Adak region located with network data, and by a lower part representing a continuation of thrusting with smaller magnitude events. The wedge-shaped zone of low-level activity, in which east-west extension predominates, is found above

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

and to the north of the thrust zone. The location, dimensions, and focal mechanisms of this region of normal faulting strongly suggest that Adak Canyon and similar features found to the west across the arc are caused by lateral extension of the over-riding plate. A M_S 7.1 shallow thrust event and four major aftershocks that occurred in the Adak Canyon region in May 1971 have been relocated by the master-event technique. The relocated sequence forms a tight cluster, about 20 km in diameter, and appears to be associated with the trenchward part of the thrust zone. This series of events lies in the center of a gap in recent large-magnitude seismicity.

● **2.1-24** Sykes, L. R., **Plate tectonic framework of Middle America and Caribbean regions and prospects for earthquake prediction,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 1, 11.

The hypothesis of plate tectonics provides a framework for discussing the great Guatemala earthquake and other seismic activity in Middle America and the Caribbean. The Caribbean plate is surrounded by a nearly continuous belt of earthquakes. Very little deformation, however, occurs within the plate itself. A number of destructive earthquakes have occurred historically along the various sides of the Caribbean plate. Nevertheless, the plate moves relatively slowly with respect to the American plates on its northern, eastern, and southern sides. The relative motion between the Caribbean and American plates is manifested in a variety of tectonic styles, which are discussed in this paper.

● **2.1-25** Dengo, G., **Tectonic framework of the Caribbean region: a historical review** (Marco tectonico de la region del Caribe: resena historica, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 2, 7.

The tectonics of the Caribbean region have been the subject of intensive investigation because of the diverse and complex geological conditions located within a relatively small area. Most attention has been directed toward obtaining a detailed knowledge of the geological structure, the underlying crust, and the tectonic history. This paper describes briefly the tectonic characteristics of the Caribbean region and neighboring areas and discusses the present mechanisms of tectonic activity.

● **2.1-26** Plafker, G., **Tectonic significance of surface faulting related to the 4 February 1976 Guatemala earthquake,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 3, 20.

The locations of surface ruptures and the main shock epicenter indicate that the disastrous Guatemala earthquake of Feb. 4, 1976, was tectonic in origin and generated mainly by slip on the Motagua fault, which has an arcuate, roughly east-west trend across central Guatemala. Fault breakage was observed for 230 km. Displacement is predominantly horizontal and sinistral with a maximum measured offset of 340 cm and an average of about 100 cm. Secondary fault breaks trending roughly north-northeast to south-southwest have been found in a zone about 20 km long and 8 km wide extending from the western suburbs of Guatemala City to near Mixco, and similar faults with more subtle surface expression probably occur elsewhere in the Guatemalan Highlands. Displacements on the secondary faults are predominantly extensional and dip-slip, with as much as 13 cm vertical offset on a single fracture.

The primary fault that broke during the earthquake involved roughly 10 percent of the length of the great transform fault system that defines the boundary between the Caribbean and North American plates. The observed sinistral displacement is striking confirmation of deductions regarding the late Cenozoic relative motion between these two crustal plates that were based largely on indirect geologic and geophysical evidence. The earthquake-related secondary faulting, together with the complex pattern of geologically young normal faults that occur in the Guatemalan Highlands and elsewhere in western Central America, suggest that the western wedge-shaped part of the Caribbean plate, roughly between the Motagua fault system and the volcanic arc, is being pulled apart in tension and left behind as the main mass of the plate moves relatively eastward.

Because of their proximity to areas of high population density, shallow-focus earthquakes that originate on the Motagua fault system, on the system of predominantly extensional faults within the western part of the Caribbean plate, and in association with volcanism may pose a more serious seismic hazard than the more numerous (but generally more distant) earthquakes that are generated in the eastward-dipping subduction zone beneath Middle America.

● **2.1-27** Donnelly, T. W., **Geological history of the Motagua Valley and of the Motagua fault system** (in English and Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 4, 3.

This paper describes the results of detailed geological mapping and related geological studies in the Motagua Valley. The fault systems of the area are described.

● **2.1-28** Schwartz, D. P., Cluff, L. S. and Donnelly, T. W., **Quaternary faulting along the Caribbean-North**

● *See **Preface**, page v, for availability of publications marked with dot.*

American plate boundary in Central America, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 6, 17.

Recent detailed maps of the zone along the Motagua fault, as well as surveys along the zones of the Chixoy-Polochic and Jocotan-Chamelecon faults, provide new information about the plate boundary between the Caribbean region and North America. The limit, south of the Motagua fault area, is defined by an active fault of major importance, with a left slip that ruptured during the Feb. 4, 1976, Guatemala earthquake. The recurrent nature of slipping along the fault is dramatically demonstrated in the zone where the terraces of the Tambor River stream show progressive left and vertical (at the north) slipping. The left slip increases from 23.7 m (the most recent terrace appearing on the maps) to 58.3 m, (the oldest terrace shown in the maps), and vertical slipping increases from 0.6 m to 2.5 m. The oldest terrace is apparently less than 40,000 yr. old but more than 10,000 yr.

Surveys along the zone of the Chixoy-Polochic fault, between Chiantla and Lake Izabal, gave way to localizing a registered line of an important active fault with left slip that had not been previously recognized. Geomorphologic aspects along this fault are similar to those observed along the active line registered in the Motagua fault area. There has been no evidence of left slip along the area of the Jocotan-Chamelecon fault zone in Guatemala.

In Central America, the active plate boundary between the Caribbean region and North America comprises the zones of the Motagua and Chixoy–Polochic faults, and probably those of the Jocotan-Chamelecon fault, each one of the accommodating parts of the slip taking place in the surroundings of Cayman, the center of the expansion. Similarity in geomorphological sections, the apparent amount of the left slip, and the frequency and magnitude of repeated seisms which were instrumentally recorded among the active lines recorded in the Motagua fault and Chixoy-Polochic zone suggest a degree of activity comparable to that of the Quaternary era. The trend and amount of Quaternary slip in the Jocotan-Chamelecon fault area remain uncertain.

● 2.1-29 Bucknam, R. C., Plafker, G. and Sharp, R. V., **Surface faulting and afterslip along the Motagua fault in Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 7, 20.

For much of its length, the 230-km-long surface rupture produced by the Feb. 4, 1976, Guatemala earthquake follows a zone of geomorphic features along the Motagua fault that is typical of major strike-slip faults. The features include offset drainages, sag ponds, springs, shutter ridges, elongate ridges, side-hill benches, and aligned drainages. These features are generally absent along the western 70 km of the fault, possibly indicating that this is a more recently activated strand within the Motagua fault system. Detailed mapping of the surface rupture focused on a descriptive account of the surface ruptures, quantitative variations in displacement along the fault, and measurement of continuing post-earthquake displacement (afterslip).

Surface rupturing on subsidiary surface faults and splays along the main fault trace are notably scarce. The surface rupture is commonly confined to a narrow zone of en echelon surface cracks and pressure ridges as much as several meters in width. Exposures of the fault at depths from 1.5 to 2 m below the surface show that displacement typically occurred along a single tightly closed slip surface. The surface expression of the displacement ranges from a narrow linear disturbed zone in damp clay-rich soils to a zone of gaping en echelon fissures connected by overthrust slabs of soil in areas of cohesive soils. The fissures and overthrust slabs are connected by a twisted surface that merges with the throughgoing slip surface at depth. Matching, well-preserved irregularities on some en echelon fissures show that the initial displacement primarily involved a component of opening perpendicular to the trend of the fissures, followed by displacement parallel to the trend of the fault zone.

Left slip along the fault, as measured in Apr. 1976, averaged 110 cm and ranged from a maximum of 340 cm, 40 km from the west end of the fault, to a minimum of 45 cm in the central portion, to 160 cm near the east end. Changes in the amount of displacement along the fault tend to be regular over distances of as much as 50 km and are terminated by short intervals of rapid variation in measured displacement. Arrays of surveyed benchmarks installed across the fault were used to document the history of continuing movement (afterslip) along the fault for nearly 2 years following the earthquake. Afterslip at one location increased displacement from 60 cm on Feb. 8, 1976, to 91 cm on Oct. 6, 1977. Afterslip time histories determined at three sites have shown the afterslip to be proportional to the logarithm of time since the earthquake and the rate of afterslip to be inversely related to the amount of slip at a site.

● 2.1-30 Bonis, S., **Unheeded geological warnings from the 1976 Guatemala earthquake,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 9, 5.

● *See **Preface,** page v, for availability of publications marked with dot.*

Foundation hazards demonstrated by the 1976 Guatemala earthquake, such as faulting, ground breaks, and landslides have received little professional or public attention since the first few weeks after the disaster. The author states that the handful of local geologists lack experience and knowledge, and foreign specialists generally do not have the requisite combination of interest and financing to address these problems. Public officials and professional organizations, partly in response to the possibly sensitive economic consequences of these inquiries, do not encourage, much less demand, investigation or research into these matters.

The Motagua fault zone, which caused the 1976 earthquake, is only one of several tectonic systems capable of generating destructive earthquakes in Guatemala. Pumice underlying much of the Guatemalan highlands shows extensive faulting within the last 90,000 years. The Guatemala City valley is bound by major faults, of which only the western system was activated in 1976. Guatemala City has been struck by two disastrous earthquakes in a span of 59 years. It is a geological certainty that there will be more. A few of the more critical earthquake problems which call for careful investigation and publicized, concrete solutions are (1) how and where to build in relation to faults and ground break; (2) how far away from canyon walls it is safe to build; and (3) what the hazards are of construction on the eastern fault scarp of the Guatemala valley.

● **2.1-31** Tocher, D., Turcotte, T. and Hobgood, J., **Seismological aspects of the Guatemalan earthquake of February 4, 1976,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 43, 15.

The magnitude 7.5 earthquake, which struck Guatemala on Feb. 4, 1976, at 3:02 a.m. local time was one of the most severe to have occurred in Central America, being accompanied by a death toll of almost 23,000, some 77,000 injuries, and damage in the range of $1.1 billion. The earthquake had a maximum modified Mercalli Scale intensity of IX; the total felt area covered some 100,000 km^2 in Guatemala, El Salvador, and Honduras. The high intensity assignments were based on vibrational effects of strong ground motion on structures rather than on the geologic effects such as extensive landsliding, ground cracks, fissures, or groundwater effects which also accompanied the earthquake.

The Motagua fault ruptured at the surface for approximately 240 km. The rupture propagated from the epicenter near the town of Los Amates, eastward a short distance toward Puerto Barrios, but mainly to the west toward Guatemala City. The focal depth of the mainshock was constrained to 5 km based on the fault rupture having extended to the surface and on the focal depth of the aftershocks. The epicenter was 15.32°N and 89.08°W, near the town of Los Amates. Teleseismic data analysis of body waves and surface waves has indicated a left-lateral displacement along a nearly vertical fault plane. Seismic moment estimates were 2.6×10^{27} and 5.4×10^{27} dyne-cm with stress drop estimates between 3 and 18 bars. Movement on a northerly trending secondary fault, the Mixco, contributed to the damage in Guatemala City and vicinity. One of the largest identifiable aftershocks of the Feb. 4 earthquake (magnitude $5.8m_b$) was possibly associated with the surface displacements observed on the Mixco fault. Normal faults with north to northeast trends, similar to the Mixco, have been identified to the south of the Motagua fault zone. There is also the suggestion of a similar trend in lineaments to the north of the Chixoy-Polochic fault. The level of activity of these features is unknown at this time, but should be studied in any regional earthquake hazard evaluation.

● **2.1-32** Fujii, Y., **Crustal interaction between the south Kanto and the Tokai district, Japan: latest crustal dynamics along the northern boundary of the Philippine sea plate** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **32,** *1,* Mar. 1979, 75-88.

Some remarkable geophysical events have prevailed since 1974 along the northern boundary of the Philippine Sea Plate. A series of crustal activities, e.g., occurrence of the 1974 Izu-hanto-oki earthquake, crustal upheaval and a related earthquake swarm in 1976, and the 1978 Izu-Oshima-kinkai earthquake, have been observed in and around the Izu Peninsula, Japan. A small crustal upheaval and related earthquake swarm activities in and near the Boso Peninsula in the south Kanto District have also been observed during approximately the same period. Recently, acceleration of crustal subsidence near the Omaezaki promontory and crustal upheaval near Mikkabi have been detected in the Tokai District. The author considers these geophysical phenomena to be related and interprets them in terms of plate tectonic theory. The upper part of the convergent boundary of the Philippine Sea Plate had been completely locked throughout the concerned period, while the deeper part slipped aseismically along some parts of the plate boundary. The Mikkabi uplift and the Omaezaki subsidence acceleration might have been caused by the aseismic down-thrusting under the Tokai District of the deepest part of the convergent plate. When subduction of the plate was accelerated at the convergent plate boundary, the acceleration propagated to another location causing an aseismic slip. As a result, a series of crustal upheavals and related earthquake activity were observed. As for the future activities of the observed geophysical events, there are two possibilities. One is the occurrence of a Tokai (Suruga Bay) earthquake as a consequence of the forward propagation of the deep dislocation to the upper part of the plate boundary. The other is stagnation of the deep creep dislocation.

● *See **Preface**, page v, for availability of publications marked with dot.*

One key in predicting a future Tokai earthquake may be the determination of which possibility is likely to occur.

● 2.1-33 Ladd, J. W. et al., **Tectonics of the Middle America trench offshore Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 5, 18.

A geophysical and geological survey conducted over the landward slope of the Middle American Trench offshore Guatemala has revealed landward-dipping reflectors which are associated with high compressional wave velocities, large magnetic anomalies, and basic and ultrabasic rock. Multifold seismic reflection data reveal that the edge of the continental shelf is a structural high on which Cretaceous and younger sediments of the shelf basin onlap and pinch out. The upper part of the continental slope is covered in most places by a 0.5 to 1.0 km thick sediment apron with seismic velocities of 2.0 to 2.5 km/sec. Immediately beneath the sediment apron an irregular surface is the top of a unit with velocities of 4.6 km/sec. Within this unit landward-dipping reflectors are traced to about 6 km below sea level. Above this zone of dipping reflectors, two positive magnetic anomalies and a positive free-air gravity anomaly are present.

The sediment apron pinches out on the lower continental slope where refraction results indicate only a few hundred meters of 2.5 km/sec material lying over about a kilometer of 3.0 km/sec sediment. Between the 3.0 km/sec sediment and a landward continuation of ocean crust, an interval of 4.1 to 4.7 km/sec material occurs which thins seaward. The interface between the 4+ km/sec material and the oceanic crust with velocities of 6.5 to 6.8 km/sec appears on reflection records as a landward-dipping horizon that can be followed about 30 km landward from the trench axis.

Coring on the continental slope returned gravels of unweathered metamorphosed basalt, serpentine, and chert, unlike rock found onshore in Guatemala. These gravels, which were probably derived from local subsea outcrops, are similar to Nicoya lithologies. A canyon cut in the outer continental shelf and upper continental slope may be associated with faulting, as indicated by recent seismicity and an offset of linear magnetic anomalies at the shelf edge. The observations of the authors are consistent with previous work that suggested slices of rock similar to Nicoya lithology are embedded in the upper slope. The lower slope is probably a tectonically deformed and consolidated sediment wedge overlying ocean crust.

● 2.1-34 Isachsen, Y. W. and Geraghty, E. P., **Ground investigations of projected traces of focal mechanisms for earthquakes at Blue Mountain Lake, Raquette Lake, and Chazy Lake, Adirondack Uplift, New York, Final report, July 1977-June 1978,** *NUREG/CR-0888,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., 1979, 33.

The surface projections of three focal mechanisms in the Proterozoic metamorphic complex of the Adirondack Mountains of northern New York State were mapped to search for evidence of faulting. In an initial study at Blue Mountain Lake conducted during a seismic episode, seven microearthquakes were heard but no ground manifestation was found. Subsequent, detailed (1:2,000) mapping of geology along 700 m of the trace of the fault plant solution failed to confirm the existence of a fault at the surface but disclosed sets of anomalous, low-angle conjugate fractures, one of which is parallel to the computed focal mechanism. This suggests that such fractures may be subtle surface indicators of fault movement at deeper levels. Gravity and magnetic mapping produced ambiguous results.

Fracture mapping along the shoreline of Raquette Lake provides indirect evidence for the existence of a high-angle fault along the NNW topographic lineament which defines the long axis of the lake. The evidence includes patches of anomalous fracturing and steeply dipping conjugate fractures which are subparallel to the lineament. The lineament does not appear to be the surface trace of a thrust fault corresponding to the focal mechanism for the 1975 earthquakes at Pilgrim Mountain.

Detailed outcrop mapping (1:24,000) of the 17 km-long, proposed Chazy Lake fault failed to provide evidence for the surface expression of the fault associated with the 1975 Altona earthquake (Nuttli magnitude 4.2). In fact, no evidence for the Chazy Lake fault, as tentatively mapped by Postel, was observed. Nevertheless, the presence of a NNW-trending break is strongly suggested by a marked aeromagnetic discontinuity. Based on abrupt foliation reorientation and other indirect evidence, it is suggested that the Chazy Lake discontinuity may be a shear zone or ductile fault with left-lateral displacement of 10-12 km.

● 2.1-35 Savage, J. C. et al., **Geodetic tilt measurements along the San Andreas fault in central California,** *Bulletin of the Seismological Society of America,* 69, *6,* Dec. 1979, 1965-1981.

Changes in tilt have been measured by annual or semiannual spirit level surveys of small-aperture (40 to 400 m) benchmark arrays located at borehole tiltmeter sites along the San Andreas fault in California. Because there are six or more benchmarks in most arrays, the tilt is overdetermined, and realistic estimates of uncertainties can be made. The large arrays (aperture 300 m) afford a precision (two standard deviations) of about 3 μrad in measuring tilt, and the measured tilt remains constant to within ± 5 μrad over periods of up to 5 years. The small arrays (aperture <100 m) afford a precision of about 6 μrad in measuring tilt, but

● *See **Preface**, page v, for availability of publications marked with dot.*

the measured tilt exhibits a high variability significant even at that level of precision. The lower precision of the small arrays is primarily a consequence of minor benchmark instabilities and local short-wavelength elevation disturbances (root mean square variability perhaps 0.25 mm), but the high variability of tilt measured by the small arrays appears to be a product of local intermediate-wavelength (50 to 300 m) elevation disturbances (perhaps caused by the mechanisms suggested by Harrison, and by Harrison and Herbst) rather than true tectonic tilting. In general, borehole tiltmeter recordings show large changes (>10 μrad) in tilt within periods on the order of a year, but the best tiltmeters exhibit a stability comparable to that obtained from surveys of the large-aperture benchmark arrays.

● **2.1-36** Liu, H.-S. and Chang, E. S., **On the selection of station sites for observing strain steps and earthquake forerunners in California,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1989-1994.

Based on seismic data for 1931 to 1960 in California and western Nevada, the authors have calculated probabilities for observing strain steps in 10 years at 729 hypothetical stations covering from 30°N to 43°N and 114°W to 127°W. As an independent test of the results, the authors have computed the number of strain steps which would have been detected at each station during the period between 1961 to 1970. Using the statistical method for detecting unusual seismic activities developed by Shimazaki, it has been found that the most favorable locations for observing crustal deformation in California are in the vicinity of Monterey and in the area surrounding San Bernardino.

● **2.1-37** Walcott, R. I., **New Zealand earthquakes and plate tectonic theory,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *2,* June 1979, 87-93.

The rates and direction of shear strain from geodetic data and the direction of slip from earthquake mechanism studies in New Zealand are in good agreement with plate tectonic theory. The relative motion of the Pacific and Indian plates in the last 100 years has been accommodated by distributed strain in a belt at least 100 km wide crossing New Zealand from northeast to southwest. Strain rates within this belt exceed 3×10^{-7}/y and average 5×10^{-7}/y in Marlborough. Under the eastern North Island and northern part of the South Island, the Pacific plate underthrusts the overlying belt of deformation. Large thrust earthquakes are episodically generated, perhaps by locking of the thrust. Not all relative plate movement is transformed into displacement on faults; a substantial fraction is taken up by aseismic and anelastic deformation within the plate boundary zone. The relative proportion of aseismic and seismic deformation may vary in different regions.

● **2.1-38** Kato, T., **Crustal movements in the Tohoku District, Japan, during the period 1900-1975, and their tectonic implications,** *Tectonophysics,* **60,** *3/4,* Dec. 1, 1979, 141-167.

Vertical crustal movements in the Tohoku District for the past 75 years are discussed with reference to their tectonic implications. For this study, the author first compiled a map of accumulated vertical movement for the past 75 years by making proper correction for closure. In addition, a new presentation technique, utilizing a time-space domain representation of elevation changes, is applied to the data. These contour maps provide an informative summary of the vertical crustal movement history in the district. From the maps, it can be seen that the northeastern part of the district has subsided continuously and aseismically, with an area of significant subsidence inland at a distance about 300 km or more from the trench axis. In order to explain the mechanism of the remarkable extension of the subsiding area, the finite element method is used to model the elastic strain field in the district. It is shown that a simple model of uniform dragging at the interface of a sinking slab does not provide a good interpretation of the inland distribution of subsidence. A modification of the conventional model is proposed which hypothesizes vertical movement of the subducting lithospheric slab under the Tohoku District.

● **2.1-39** **New England seismotectonic study activities during fiscal year 1978,** *NUREG/CR-0939,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., 1978, 179.

A six-year program to investigate seismicity in New England and adjacent areas and to delineate the seismic hazard within the region began July 1, 1976. The study is a cooperative effort with several universities and state and federal Geological Surveys and is coordinated with the programs of the Northeastern U.S. Seismic Network and the U.S. Army Corps of Engineers. Causes of moderate but persistent seismic activity in the region have been difficult to assess because of a paucity of geologic and seismologic data. The program is correcting this by providing: (1) regional information needed to understand seismicity and its relation to geologic features and to delineate seismotectonic provinces, and (2) more detailed data in the areas of higher seismicity to reveal relations of seismicity with geology and to identify active features. Regional and detailed studies will evaluate various hypotheses proposed to explain causes of earthquakes in the region and to delineate zones of differing seismic hazard. Results thus far document the importance of faulting in New England and demonstrate the effectiveness of remote-sensing, magnetic-lineament, and gravity-lineament analyses to reveal faults in the region. Present data indicate that the more information available on earthquake locations and faults in an area, the

● *See **Preface**, page v, for availability of publications marked with dot.*

closer the spatial relation of earthquakes with faults, but no fault has yet been proven to be active.

2.1-40 Aralbaev, A. A., Kabo, A. E. and Shakirov, E. Sh., **Some geological-geophysical data on the seismotectonics of the Frunze municipal area** (Nekotorye geologo-geofizicheskie dannye o seismotektonike poligona g. Frunze, in Russian), *Geologo-Geofizicheskie Osobennosti i Seismichnost' Territorii Kirgizii,* Ilim, Frunze, U.S.S.R., 1978, 90–98.

Brief results are presented of integrated geological-geophysical studies of the tectonic structure of the Frunze municipal area. Special attention is given to the possible existence and seismogenicity of a northeast-striking fault in the southwestern portion of the city. Seismological, geophysical, and geological data are cited in reassigning the southern part of the city of Frunze to the 8-point seismic risk zone instead of the 9-point rating assigned in early microzoning of the area.

2.1-41 Shakirov, E. Sh., Shvartsman, Yu. G. and Palamarchuk, V. K., **Deep structure of northern Kirghizia and its relationship to seismic and geothermal activity** (Osobennosti glubinnogo stroeniya severnoi Kirgizii i ikh svyaz' s seismichnost'yu i geotermiei, in Russian), *Geologo-Geofizicheskie Osobennosti i Seismichnost' Territorii Kirgizii,* Ilim, Frunze, U.S.S.R., 1978, 30–37.

Results of field geophysical research of seismic and geothermal behavior are reported. A comprehensive analysis of aeromagnetic survey data of the seismic and geothermal activity of a portion of northern Kirghizia brings to light some major regional structural elements of the territory, while demonstrating recent seismic and tectonic activity.

● **2.1-42** Crandell, D. R. and Mullineaux, D. R., **Potential hazards from future eruptions of Mount St. Helens Volcano, Washington,** *U.S. Geological Survey Bulletin 1383-C,* U.S. Government Printing Office, Washington, D. C., 1978, 26.

2.1-43 **Geological and geophysical characteristics of seismogenic zones of Kirghizia** (Geologo-geofizicheskaya kharakteristika seismogennykh zon Kirgizii, in Russian), Ilim, Frunze, U.S.S.R., 1978, 160.

The collection of papers contains material on the deep structure and seismicity of the Tian-Shan mountainous area in Kirghizia, U.S.S.R. Data needed for the solution of some applied problems are presented; the data are useful specifically in earthquake forecasting and in compiling seismic microzoning maps. Techniques useful in studying features of the geological structure of seismogenic zones are described.

2.1-44 Savage, J. C. et al., **Geodolite measurements of deformation near Hollister, California, 1971-1978,** *Journal of Geophysical Research,* 84, *B13,* Paper 9B1079, Dec. 10, 1979, 7599–7615.

A 24-station trilateration network spanning the San Andreas and Calaveras faults near Hollister, California, has been surveyed each year between 1971 and 1978. Two moderate ($M_L = 5$) earthquakes have occurred within the network during the interval. No convincing preseismic or coseismic anomalies associated with those earthquakes have been identified. The deformation of the network can be described roughly by rigid body motion of the three blocks bounded by the two faults with accommodation occurring by right-lateral strike slip on the San Andreas (13 ± 2 mm/a) and Calaveras (17 ± 2 mm/a) faults. The required slip rates are within the range of the observed fault creep on those faults. A more detailed analysis of the deformation indicates appreciable strain accumulation (0.4 μstrain/a tensor shear) within the block lying between the San Andreas and Calaveras faults. Many of the features of the observed deformation can be produced by an elementary dislocation model, indicating that most of the deformation is associated directly with slip on the major faults. The network is not extensive enough to define uniquely the relative motion across the San Andreas fault system, but the data are consistent with a value of about 38 mm/a. The rate of deformation in 1971-1978 was not uniform but rather appears to have been higher than normal in 1973-1974 and lower than normal in 1975-1976.

2.1-45 Johnston, M. J. S. et al., **Tectonomagnetic anomaly during the southern California downwarp,** *Journal of Geophysical Research,* 84, *B11,* Paper 9B0524, Oct. 10, 1979, 6026–6030.

Resurveys of the local geomagnetic field in southern California, using magnetometers in a differential mode, indicate the development of an anomalous field of more than 10 γ that appears to correspond to the partial collapse of the southern California uplift. The 10-γ field increase occurred within a 30-km fault segment near the junction of the San Andreas and San Jacinto faults. It took place episodically in time, with 80% accumulated between late 1973 and the end of 1974 and the remaining 20% between 1974 and 1976. Changes of smaller maximum amplitude and in an opposite sense occurred to the southeast along the San Jacinto fault. Swarm seismicity started at the northwest end of the zone of maximum anomaly in late 1976 but ceased in late 1977. The anomaly amplitude has slowly decreased with time since its peak in 1976. Tectonomagnetic models imply localized stress changes at depths of at least 10 bars in the vicinity of the magnetometer sites near the various faults, although details concerning the geometry and dimensions of the region responsible for the magnetic field changes are poorly resolved.

● *See **Preface**, page v, for availability of publications marked with dot.*

2.2 Wave Propagation

● **2.2-1** Miller, R. K., **An estimate of the properties of Love-type surface waves in a frictionally bonded layer,** *Bulletin of the Seismological Society of America,* **69,** *2,* Apr. 1979, 305-317.

An approximate analytical approach is presented for determining the attenuation, dispersion, and intensity of motion at depth associated with Love-type surface waves in an elastic layer bonded by Coulomb friction to an elastic halfspace. It is found that the dispersion curves are only slightly affected by a small amount of slip at the interface, but that the level of attenuation in the system increases considerably with the amplitude of motion. The results for the frequency dependence of the attenuation in the system are in basic agreement with experimental data on the attenuation of Love waves in the earth. The results for the intensity of motion at depth indicate a deterioration of bonding at high frequencies.

● **2.2-2** Lee, W. B. and Solomon, S. C., **Simultaneous inversion of surface-wave phase velocity and attenuation: Rayleigh and Love waves over continental and oceanic paths,** *Bulletin of the Seismological Society of America,* **69,** *1,* Feb. 1979, 65-95.

A formalism for the simultaneous inversion of surface-wave phase velocity and attenuation, previously developed for Love waves, is extended in this paper to Rayleigh waves. The simultaneous inversion technique permits the specification of the intrinsic dispersion-attenuation relation that arises from linearity and causality, and takes full account of the dependence of surface-wave phase velocity and Q^{-1} on the real and imaginary parts of an anelastic earth structure. The formalism, including resolution analysis and extremal inversion, is applied to combined Love- and Rayleigh-wave data sets for a tectonically active and a stable continental path and to Rayleigh-wave data for a stable oceanic path. The depth to the low Q zone, is 60 ± 20 km for the central Pacific, 80 ± 20 km for western North America, and 130 ± 30 km for east-central North America. Q^{-1} within the low-Q, low-velocity zone, however, is greater beneath western North America than beneath the central Pacific; the low-Q zone beneath east-central North America need not be a low-velocity zone at frequencies above 1 Hz. The surface-wave data cannot be used to distinguish among several possible intrinsic, dispersion-attenuation relations for the upper mantle.

● **2.2-3** Bollinger, G. A., **Attenuation of the *Lg* phase and the determination of m_b in the southeastern United States,** *Bulletin of the Seismological Society of America,* **69,** *1,* Feb. 1979, 45-63.

A study of the *Lg* radiation from 17 southeastern U.S. earthquakes shows the attenuation of that phase to be at a $0.07^{\circ-1}$ rate for epicentral distances of 100 to 700 km. At longer distances, it is also at that rate for some of the earthquakes, but for five of the events it was at a somewhat greater ($0.10^{\circ-1}$) rate. These different *Lg* attenuation rates are clearly a distance-related effect, but they are not caused by differences in source area, propagation path, radiation pattern, wave period, or group velocity. A possible explanation for the different attenuation rates is a shift from a normal-mode form of propagation to a leaking-mode form, brought about by slight phase-velocity variations in the crustal wave guide and/or in the underlying layer. Also, the influence of lateral heterogeneity and variations in the thickness of the crustal wave guide offer alternative explanations.

Nuttli's $m_b(Lg)$ formulas, determined for central U.S. events, were found to be appropriate for use on southeastern U.S. shocks if their application is restricted to epicentral distances less than 2,000 km. This distance restriction result agrees with that determined for northeastern U.S. earthquakes by Street.

● **2.2-4** Daley, P. F. and Hron, F., ***SH* waves in layered transversely isotropic media—an asymptotic expansion approach,** *Bulletin of the Seismological Society of America,* **69,** *3,* June 1979, 689-711.

An asymptotic expansion of the displacement vector in terms of inverse powers of frequency is used to investigate the dynamic (amplitude) properties of *SH* waves propagating in plane-layered transversely isotropic media. Both reflected and head waves are considered in terms of the asymptotic expansion, and their ranges of validity and accuracy are discussed. Although the solution of the most general case of wave propagation in an anisotropic medium has been presented in the literature, it is instructive to consider this simple case in which many quantities inherent to wave propagation in anisotropic media can be more readily understood and can be solved analytically rather than reverting to numerical methods.

● **2.2-5** Maiti, N. C. and Mitra, M., **Wave propagation from extended, asymmetric surface sources in an elastic half-space,** *Bulletin of the Seismological Society of America,* **69,** *3,* June 1979, 713-735.

A procedure is given for the exact determination of the displacement produced in a halfspace by arbitrary stresses acting on the surface. Solutions are obtained for three different impulsive stress distributions acting on a circular portion of the surface, and some common features of the solutions are examined. Numerical values of the surface displacement are exhibited graphically in the three cases showing that the pulses comprising the surface motion are oscillatory.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● 2.2-6 Shiono, K., Ohta, Y. and Kudo, K., **Observation of 1- to 5-sec microtremors and their application to earthquake engineering. Part VI; existence of Rayleigh wave components** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* 32, 2, June 1979, 115-124.

In a previous paper, the authors have interpreted long-period microtremors to be an ensemble of dispersive surface waves (Rayleigh and Love). As a continuation of this research, a more detailed examination of the Rayleigh wave component is carried out and reported in this paper. Phase velocity, particle motion, and a deposit/basement spectral amplitude ratio are analyzed and used to study the structure of the Rayleigh wave modes. Because long-period microtremors are composed of Rayleigh and Love waves, the authors advocate that Love waves also be studied.

2.2-7 Sinitsyn, A. P., **Seismic waves in frozen soil** (Seismicheskie volny v zamorozhennom grunte, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 3-10.

A computational model for determining temperature fields in frozen soil is discussed. It is found that changes in the temperature field take place cyclically, with velocity profiles varying in same cycle. An analysis is presented of changes in the speeds of propagation of longitudinal seismic waves.

2.3 Source Mechanisms

● 2.3-1 Singh, D. D. and Gupta, H. K., **Source mechanism and surface-wave attenuation studies for Tibet earthquake of July 14, 1973,** *Bulletin of the Seismological Society of America,* 69, 3, June 1979, 737-756.

The focal mechanism for the Tibet earthquake of July 14, 1973 (M = 6.9, m_b = 6.0) is determined using the P-wave first motions, S-wave polarization angles, and surface-wave spectral data. A normal faulting is obtained with a plane having a strike of N3°W, a dip of 51°W, and a slip angle of 81°. The source parameters are estimated for this event using the body-wave and surface-wave spectra. The seismic moment, fault length, apparent stress, stress drop, seismic energy release, average dislocation, and fault area are estimated to be 2.96 X 10^{26} dyne-cm, 27.4 km, 14 bars, 51 bars, 1.4 X 10^{22} ergs, 157 cm, and 628 km^2, respectively. The high stress drop and apparent stress associated with this earthquake indicate that high stresses are prevailing in this region. The specific quality factor Q is found to vary from 21 to 1162 and 22 to 1110 for Rayleigh and Love waves, respectively. These wide ranges of variation in the attenuation data may be a result of the presence of heterogeneity in the crust and upper mantle.

● 2.3-2 Denham, D., **Summary of earthquake focal mechanisms for the western Pacific-Indonesian region, 1929-1973,** *Report SE-3,* World Data Center A for Solid Earth Geophysics, U.S. National Oceanic and Atmospheric Admin., Boulder, Colorado, Mar. 1977, 110.

This report reproduces in its entirety the present catalog of earthquakes in the western Pacific-Indonesian region from 1929-1973. The catalog contains 1713 solutions from 48 data sources in tabular form. Most solutions are from earthquakes that have taken place since 1960, when the worldwide standard seismograph system became operational. However, a few solutions for earlier earthquakes are included if they are based on reliable observations. The earliest earthquake in the catalog occurred on June 2, 1929, south of Nagoya, Japan. The catalog includes the data source, date and time (UT), epicenter, and magnitude of each earthquake (MB, ML, or MS). The poles of the two nodal planes, and the compression, tension, and null axes are provided for each of the earthquakes in the list. The azimuths are always taken clockwise from the north, and the plunge is the angle the axis or pole makes with the horizontal.

Several sources did not include all the focal parameters, and the main purpose in compiling this catalog was to fill these gaps. Magnitudes and hypocentral parameters were taken from the bulletins of the International Seismological Center; the missing focal mechanism parameters were calculated manually. In all the calculations, a standard orthogonal double-couple model was used. Although it is desirable to list all five parameters, some publications contain only the parameters of the nodal planes. This practice should be discouraged because these parameters are not sufficient to define the stress regime at the earthquake focus. If only two parameters of a solution are listed, it is preferable that these be the pressure and tension axes. The catalog is available in computer-readable form, both as a card deck and as card images on magnetic tape.

● 2.3-3 Shimazaki, K. and Somerville, P., **Static and dynamic parameters of the Izu-Oshima, Japan earthquake of January 14, 1978,** *Bulletin of the Seismological Society of America,* 69, 5, Oct. 1979, 1343-1378.

The static and dynamic parameters of the M_S = 6.8 Izu-Oshima earthquake were determined from far-field SH wave forms, near-field displacement-type strong-motion seismograms, surface-wave spectral amplitudes, and static displacements in the vicinity of the fault. The main shock involved right-lateral strike-slip motion together with a small normal dip-slip component on an EW trending, steeply northward dipping fault plane which lies under the sea between the Izu Peninsula and Izu-Oshima. The mean seismic moment estimated from surface-wave and SH-wave amplitudes is close to the value estimated independently from geodetic data, implying that the rupture process inferred from seismic waves represents the main faulting process. The total length of this fault and a buried subsidiary (and possibly aseismic) inland fault is less than

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

half the overall extent of the aftershock zone which extends from Izu-Oshima right across the Izu Peninsula. Anomalous uplift near Ito on the northeast corner of the Izu Peninsula which occurred in 1975 appears to be mechanically related to the Izu-Oshima earthquake, because the $M = 7.0$ north Izu earthquake of 1930, which involved left-lateral slip on the N-S striking Tanna fault, was also preceded by anomalous uplift near Ito. This conjugate fault pair reflects NW-SE compressional stress and may be regarded as accommodating NW-SE shortening in the vicinity of the collision zone between the Philippine Sea plate and the Eurasian plate. The parameter values of the earthquake are given in the paper.

● 2.3-4 Sato, T. et al., **A source model for explaining the predominant directions of the ground motion inferred from the damages to gravestones and houses** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **32**, *2*, June 1979, 171–182.

The modes and the degrees of damage caused by the Onikobe, Japan, earthquake ($M = 4.9$) of July 5, 1976, were investigated with special reference to the predominant direction of the ground motion. The directions of falling and slip of gravestones near the focal region were restricted to a narrow range of directions, and these data were found useful for estimating the predominant direction of the ground motion. On the basis of seismological data such as the hypocenter location, the focal mechanism, and aftershock distribution, various dynamic-source models were tested in order to determine the predominant direction near the focal region. As a result, precise determination of the hypocenter location was possible, and the finally selected model explained the systematic pattern of the predominant directions observed near the focal region.

● 2.3-5 Toksoz, M. N. and Aki, K., **A study of New England seismicity with emphasis on Massachusetts and New Hampshire,** *NUREG/CR-1186,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Jan. 1980, 159.

Teleseismic P-wave arrival times recorded by the northeastern seismic network are used to invert for lateral crust and upper mantle structure to depths of 500 km. Three-dimensional inversion of the travel time data between two ancient orogenic provinces suggests that structures down to possibly 200 km and greater can be correlated with surficial geologic and tectonic features. This has the important implication that major orogenic belts have effects that reach well into the lithosphere which are stable for extended periods of time, perhaps as long as one billion years. The crust beneath the Paleozoic Appalachian province is characterized by slightly greater thicknesses and lower average velocities than that of the Precambrian Grenville province. The higher average velocities associated with the Grenville province extend to depths of 200 km and appear to be maximum beneath the Adirondack dome. A relatively low-velocity anomaly extending to depths in excess of 200 km and dipping to the northwest shows a spatial correlation with the Bronson Hill-Boundary Mountains Anticlinorium in central New Hampshire and Maine. These structures occupy the sites of a complex series of island arc sequences last active in Early Devonian time prior to the Acadian orogeny. This low-velocity region may represent subducted oceanic lithosphere which has undergone post-orogenic radioactive heating.

● 2.3-6 Reyes, A., Brune, J. N. and Lomnitz, C., **Source mechanism and aftershock study of the Colima, Mexico earthquake of January 30, 1973,** *Bulletin of the Seismological Society of America,* **69**, *6*, Dec. 1979, 1819–1840.

The Colima earthquake (magnitude 7.5) occurred just inland from the Middle America Trench, 110 km south of the Volcan de Colima and 160 km southeast of Manzanillo, Colima, Mexico. Damage at several cities and towns was severe, 30 people were killed, and hundreds were injured. Four days after the earthquake, a six-station portable seismograph array was set up in the epicentral area as part of a cooperative program between the Univ. of California at San Diego, the Univ. of Mexico, and the Mexican Federal Power Commission. From about 330 aftershocks recorded in the following 2 1/2 weeks, accurate locations were obtained for 50. One large aftershock had a magnitude of 6.2; the others ranged in local magnitude from 1.5 to 4.5. The locations outlined a region approximately 90 km long and 60 km wide, in nearly the same location as the aftershock zone inferred by Kelleher for the 1941 earthquake. The focal depth of the aftershocks (ranging from 2 to 30 km) and the fault-plane solutions for the main event indicated a shallow dipping thrust plane (about 30°). The seismic moment estimated from mantle Rayleigh waves was 3×10^{27} dyne-cm. The pattern of aftershocks was used to estimate the source dimensions. From the moment and source dimensions, the average slip was estimated to be about 1.4 m, corresponding to a stress drop of about 8 bars. The occurrence of this earthquake is discussed in terms of the general seismicity of the Middle America Trench, the convergence rate predicted by plate tectonics, and the use of seismic gap theory for earthquake prediction. The fact that this earthquake may have been in the zone of the 1941 earthquake, rather than in the adjacent seismic gap, suggests that caution must be taken in using seismic gap theory to predict earthquakes in the region. It further suggests that in the adjacent seismic gap a large earthquake may be imminent, and thus the gap may be an important area for deploying seismic instruments.

2.3-7 Nguyen, D. X., **Macroscopic field and sources of strong earthquakes in northern Vietnam** (Makroseismicheskoe pole i ochagi sil'nykh zemletryasenii v severnom V'etname, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 63–77.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

Macroseismic data collected in northern Vietnam are used to derive equations of the normal macroseismic field and to determine the basic parameters of strong earthquake foci. Data are obtained on the dimensions and location of foci in interpretation of the field anomalies. The results imply that the position and orientation of foci of strong earthquakes agree closely with the position of principal faults, and that the earthquakes occurred within the earth's crust.

● 2.3-8 Cipar, J., **Source processes of the Haicheng, China earthquake from observations of *P* and *S* waves,** *Bulletin of the Seismological Society of America,* 69, 6, Dec. 1979, 1903–1916.

The Haicheng earthquake of Feb. 4, 1975, was the first major seismic event to be predicted. In this paper, long-period teleseismic *P*- waves and *S*- waves from this event are compared directly to time-domain synthetic seismograms to infer the source parameters. Results indicate the focal mechanism of the earthquake is nearly left-lateral strike slip along a northwest striking nodal plane (strike = 288°, dip = 78° N, rake = 342°). The strike of this nodal plane agrees with the trend of the aftershock distribution. The seismic moment is 3 x 10^{26} dyne-cm and the source duration is 7 sec. Azimuthal variation of *P*-wave duration is attributed to fault propagation in a northwesterly direction along the strike of the aftershock zone. A model with a fault length of 22 km and rupture velocity of 3.2 km/sec can explain the observed *P*- waves quite well. There is considerable discrepancy between observed *SH*- waves and synthetics computed using this model. These discrepancies are caused by source structure complexities and/or changes of fault mechanism as the rupture propagated along a strike. The average dislocation is computed to be 2.8 m and the stress drop is 53 bars.

● 2.3-9 Slunga, R., **Source mechanism of a Baltic earthquake inferred from surface-wave recordings,** *Bulletin of the Seismological Society of America,* 69, 6, Dec. 1979, 1931–1964.

Surface waves generated by the earthquake on Oct. 25, 1976, in the Gulf of Finland and recorded by the North European long-period instruments in the distance range 1 to 10 degrees have been inverted in an attempt to find the fault mechanism. The resulting solution gives a very good fit between the theoretical and the observed surface waves. This intraplate earthquake was mainly of the strike-slip type, but contained a significant part of reverse dip-slip faulting, possibly amounting to up to half the strike slip. The seismic moment was in the range of 3 to 4 x 10^{22} dyne-cm, and the focal depth was 10 to 14 km. This earthquake was probably the largest in this area for at least 350 years. The body-wave magnitude was 4.5, which value is too low to give a teleseismic *P*-wave fault mechanism. However, the only clear teleseismic body-wave observation found by the author is in good agreement with the surface-wave solution, assuming the radius of the fault area to have been less than 1 km. This corresponds to a stress drop larger than 15 bars. The direction of compressional stress given by the fault solution was WNW-ESE, which is in agreement with the general stress pattern of Northern Europe proposed in several published studies. One of the two possible fault planes is in agreement with geological features of the source area.

● 2.3-10 Morgan, F. D. and Aki, K., **A surface wave study of source mechanisms of southeastern Caribbean earthquakes,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 28–43. (For a full bibliographic citation, see Abstract No. 1.2-21.)

In recent years, it has been postulated that island arcs terminate with hinge-type faulting. Such a mechanism has indeed been suggested for the southern termination of the West Indian island arc, and this is probably the reason for the complex seismicity experienced in the area. The present study utilizes surface waves to determine focal mechanisms of earthquakes in this region, with $M_b \gtrsim 5$, occurring during the period 1964-1975. Using these source mechanisms, and others from the literature, the authors discuss the hinge-type hypothesis and the regional geology. It is concluded that the earthquakes are indeed indicative of some type of hinge faulting. The area represents the junction of three plates (Caribbean, Atlantic, and South American). Earthquakes representing the junction between the Caribbean and South American are shallow (<50 km) and are right lateral strike slip. The deeper events (50-150 km) show reverse faulting with a strong left-lateral component. These earthquakes are apparently generated within a subducting zone dipping to the northwest and marking the southern termination of subduction along the West Indian island arc system.

2.3-11 Furumoto, M., **Initial phase analysis of *R* waves from great earthquakes,** *Journal of Geophysical Research,* 84, *B12,* Paper 9B0928, Nov. 10, 1979, 6867–6874.

Phase equalization was carried out for *R* waves in order to obtain information on the source mechanisms of four earthquakes, the Kurile earthquake of 1963, its largest aftershock, the Rat Island earthquake of 1965, and the Tokachi-oki earthquake of 1968. The initial phase was computed using the corresponding complete great-circle phase velocity, so that influences of the lateral heterogeneity of the earth's structure were considerably reduced. The fault length of the Kurile earthquake was determined from the initial phase radiation pattern on the basis of a simple propagating fault model. There is no tradeoff in this method between the fault length and the rupture velocity. Such a tradeoff is inherent to the conventional directivity method. A fault length of 250 km was obtained, which was found to be nearly equal to the length of the aftershock

● See *Preface,* page v, for availability of publications marked with dot.

area. A dynamic fault parameter source time is introduced that can be determined from the phase measurement using the complete great-circle phase velocity rather than the average phase velocity of the individual multiple R waves. This quantity corresponds to the rise time of the source time function of an equivalent point source. Source times of 97, 62, 174, and 115 s were obtained for the above four earthquakes.

2.4 Seismicity, Seismic Regionalization, Earthquake Risk, Statistics and Probability Analysis

● 2.4-1 Chandra, U., McWhorter, J. G. and Nowroozi, A. A., **Attenuation of intensities in Iran,** *Bulletin of the Seismological Society of America,* **69,** *1,* Feb. 1979, 237–250.

The isoseismal maps for twelve earthquakes in different parts of Iran were analyzed to study the attenuation of intensities with distance. The degree of attenuation is quite sensitive to the selection of epicentral intensities for the earthquakes considered. A graphical method presented in this paper provides a consistent basis for the estimation of epicentral intensities, for different earthquakes, from the intensity-distance plot. The attenuation relations were derived by using an iterative least squares fit procedure, whereby an initial approximate estimate of epicentral intensity for each earthquake is successively improved. Because the isoseismal maps for a number of earthquakes are elongated in the direction of local structural trend/causative faults, three different attenuation relations were derived. Intensities, on the average, attenuate slightly faster in Iran than in the San Andreas province identified by Howell and Schultz.

● 2.4-2 Anderson, J. G., **Estimating the seismicity from geological structure for seismic risk studies,** *Bulletin of the Seismological Society of America,* **69,** *1,* Feb. 1979, 135–158.

Starting with geological data, this paper estimates the seismicity for applications in seismic risk studies. The rate at which seismic moment is released can be estimated on a fault when the slip rate is known. It can also be estimated in a region of crustal convergence (without subduction) or divergence when the rate at which opposite sides of the zone are converging or the regional strain rate is known. Then, provided all the deformation is released seismically, by assuming the relative frequency of different sizes of earthquakes, the absolute frequency of events can be obtained.

The procedure is used to estimate seismicity in southern California. A review of geological literature provided preliminary estimates of slip rates on many important faults. The estimates of the seismicity resulting from these slip rates are consistent with historical records of earthquake occurrences for southern California taken as a whole. For smaller regions or individual faults in southern California, the seismicity estimated from slip rates may differ from historical rates of seismicity by a factor of two or more. In the western basin and range region, the historical seismicity is also consistent with an estimate for the strain rate. Because of this agreement in larger regions, where many faults are involved, it is inferred that the geological data is also useful for studies of smaller regions, even though on this scale the model cannot be tested because of the short earthquake historical record.

● 2.4-3 Street, R. and Lacroix, A., **An empirical study of New England seismicity: 1727–1977,** *Bulletin of the Seismological Society of America,* **69,** *1,* Feb. 1979, 159–175.

Isoseismal map measurements and magnitudes of several recent central and northeastern North American earthquakes are related by multiple regression analysis in order that m_{bLg} magnitudes can be estimated for those noninstrumentally recorded New England events for which the total felt area is known to be $\geq$ 10,000 km^2 and which occurred after 1727. Magnitude estimates of the noninstrumentally recorded events permit New England seismicity to be studied on a basis other than the heretofore conventional maximum epicentral intensity approach.

● 2.4-4 Malone, S. D. and Bor, S.-S., **Attenuation patterns in the Pacific Northwest based on intensity data and the location of the 1872 North Cascades earthquake,** *Bulletin of the Seismological Society of America,* **69,** *2,* Apr. 1979, 531–546.

Intensity data from 14 historic earthquakes in or near Washington State, as reported at over 300 localities, are used to study the attenuation structure in Washington. The empirical relation of Evernden is used to determine the size and depth for each earthquake and the local attenuation factor, k, for two physiographic parts of the state. The value for k in the Puget Sound region and north into Canada is 1 3/4, while k = 1 1/2 is more appropriate for eastern Washington and northern Oregon. Individual local amplification factors are computed for all localities at which four or more earthquakes have been felt by averaging the difference between the computed intensity and reported intensity at each site. By means of these correction factors, the authors use the intensities for the North Cascade earthquake of 1872 to place constraints on the earthquake's size and location. It appears this earthquake may be slightly large (magnitude 7.4) and located south and west of the original epicenter determined by Milne.

● *See **Preface,** page v, for availability of publications marked with dot.*

● **2.4-5** Winkler, L., **Catalog of U.S. earthquakes before the year 1850,** *Bulletin of the Seismological Society of America,* **69**, 2, Apr. 1979, 569–602.

This is a catalog of earthquakes for the United States, east of the Rocky Mountains, before the year 1850. Data and a chronological summary are presented for the northeast, east, and central U.S. Gregorian dates, local times, and modified Mercalli intensities are used. Because of the large number of entries and the great complexity of many of the entries, only references are given rather than quotations of the earthquake descriptions.

● **2.4-6** Quittmeyer, R. C. and Jacob, K. H., **Historical and modern seismicity of Pakistan, Afghanistan, northwestern India, and southeastern Iran,** *Bulletin of the Seismological Society of America,* **69**, *3,* June 1979, 773–823.

Both historical (noninstrumental) and modern (instrumental) data are compiled and critically reviewed to document the seismicity of Pakistan, Afghanistan, northwestern India, southeastern Iran, and neighboring areas. Earthquakes occurring between 1914 and 1965 are systematically relocated, and magnitudes are determined for these events when possible. For some of the larger earthquakes, in both historical and modern times, the orientation and length of the rupture zone and an approximate value of the seismic moment are estimated.

The usefulness of the documented seismicity to locate the sites of future large earthquakes in this part of the world is limited. The restricted historical record, the occurrence of earthquakes over wide zones (i.e., less confined than at oceanic subduction zones), and the long recurrence intervals combine to make the identification of seismic gaps, with a significant potential for rupture during large earthquakes, a difficult procedure. Seismicity variations prior to the great earthquake in 1945 in the Makran region along the southern coast of Pakistan appear to be consistent with patterns identified before large earthquakes elsewhere in the world. Recent patterns of seismicity farther west along the Makran coast may be consistent with those for a zone which may experience a large future earthquake; however, this observation is based on a limited amount of data.

● **2.4-7** Chinnery, M. A., **A comparison of the seismicity of three regions of the eastern U.S.,** *Bulletin of the Seismological Society of America,* **69**, *3,* June 1979, 757–772.

Frequency-intensity data from the southeastern United States, the central Mississippi Valley, and southern New England are compared. The data plots are parallel to one another and consistent with a slope of about 0.57. There is no evidence for the existence of upper bounds to the maximum epicentral intensity in these data sets. Linear extrapolation of the frequency-intensity data to intensities of X leads to expected probabilities for the occurrence of large earthquakes. The largest events which have occurred in these three regions are consistent with these probabilities.

● **2.4-8** Talwani, P. et al., **An earthquake swarm at Lake Keowee, South Carolina,** *Bulletin of the Seismological Society of America,* **69**, *3,* June 1979, 825–841.

An earthquake swarm occurred near Lake Keowee, South Carolina, in Jan. and Feb. 1978. The swarm was monitored by using portable seismographs. The shallow (<3 km), low level ($M_L \leq 2.2$), intense (up to 200 events per day) activity occurred in a narrow elliptical epicentral region (2 by 3 km). This active area trends NW-SE, normal to local geologic grain, and appears to be related to the steeply dipping NE trending joints. A search for earlier seismicity in the area suggests that this swarm is possibly related to the Seneca earthquake of 1971 which followed the impounding of Lake Keowee.

● **2.4-9** Klein, F. W., **Earthquakes in Lassen Volcanic National Park, California,** *Bulletin of the Seismological Society of America,* **69**, *3,* June 1979, 867–875.

A small seismograph network of six stations monitors earthquakes in and near Lassen Volcanic National Park. The first 14 months of recording revealed a northwest-trending seismic zone passing through the park. This zone is the resolved equivalent of a diffuse zone of historical epicenters passing through Lassen Park and Truckee, California, and is parallel to nearby lineaments in California, Oregon, and Nevada recognized from surface geology. Three dense concentrations of earthquakes correlate very closely with three geothermal areas. One concentration also outlines the north and east sides of the 4-km-diameter Mt. Tehama caldera. The recent dacite plug domes of Lassen Peak and Chaos Crags are nearly aseismic, however. Several approximate focal mechanism solutions indicate primarily normal faulting with east-west extension. This implies the northwest-trending seismic zone is undergoing extension and right-lateral shear. Extension directions near the center of the network display a radial symmetry that could be caused by a broad updoming or magma injection centered near Lassen Peak or Chaos Crags.

● **2.4-10** McGuire, R. K., **Adequacy of simple probability models for calculating felt-shaking hazard, using the Chinese earthquake catalog,** *Bulletin of the Seismological Society of America,* **69**, *3,* June 1979, 877–892.

The Chinese earthquake catalog is used to evaluate the adequacy of simple methods for calculating seismic hazards. These simple methods use a time-stationary model for seismicity and an exponential distribution for earthquake size. Earthquake occurrences in five provinces of North China (the area with the most complete history) during

● *See **Preface**, page v, for availability of publications marked with dot.*

time segments of three lengths (50, 100, and 200 years) are used as input to the hazard analysis. The probabilities of felt shaking in 62 cities in North China are calculated for the 50-year period following each time segment and are compared to the observed occurrences of felt shaking during the 50-year period. Data intervals of 50 and 100 years suffice for accurate estimation of probabilities of felt shaking; 200 years of earthquake history lead to poorer estimates of these probabilities if the rate of earthquake occurrence is averaged over the entire 200 years. This inaccuracy results from the apparent periodicity of activity in North China, which has a cycle of about 300 years. The implication is that, at a specific time, the most recent seismic activity is the best data base to use for calculation of probabilities of felt shaking in the near future.

● **2.4-11** Molnar, P., **Earthquake recurrence intervals and plate tectonics,** *Bulletin of the Seismological Society of America,* **69,** *1,* Feb. 1979, 115–133.

The frequency of occurrence of earthquakes with different seismic moments is expressed in terms of the rate of slip on a fault and the largest seismic moment likely to occur in the region. Beginning with the Gutenberg-Richter empirical expression relating the relative recurrence of events with different magnitudes and using another empirical relation for magnitude and seismic moment, the paper presents an equation for the relative number of events with seismic moment greater than or equal to M_0. From average rates of slip on faults, this expression can be used to give the recurrence rates for events of different seismic moments. A similar expression can be given for regions where deformation is distributed over a broad area without a major throughgoing fault. Using rates of convergence at island arcs determined from plate motions for the last 5 m.y., the calculated frequency of occurrence of earthquakes with large seismic moments agrees well with the historic record. At present, uncertainties in the requisite parameters and in assumptions on which the recurrence relation is based, however, make such an approach only marginally better than reliance on the historic record alone. As an example, the formulas are applied to the southeastern Caribbean.

● **2.4-12** Omote, S. et al., **A new proposal for estimating the expected maximum earthquake force at a nuclear power plant site,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 1–20.

Nuclear power plants built in seismic zones should be designed and constructed in such a way that they produce no radiation hazard, even if subjected to severe earthquakes. In order to find a reasonable solution for this problem, it is necessary first to estimate the maximum earthquake force expected at the site. This paper discusses the most commonly held ideas in Japan about this problem. The level of the strongest design earthquake, S_1, and the extreme design earthquake, S_2, are explained, and methods for deriving S_1 and S_2 earthquakes on active faults are also described.

● **2.4-13** Rogers, A. M. and Malkiel, A., **A study of earthquakes in the Permian basin of Texas-New Mexico,** *Bulletin of the Seismological Society of America,* **69,** *3,* June 1979, 843–865.

A microearthquake seismograph network has been employed to study earthquakes occurring in the Permian basin of Texas and New Mexico. The earthquakes are predominantly located on the Central basin platform, although a few occur in the Delaware basin. The majority of the earthquakes occur at the depths of sedimentary rocks, and the focal depths are also coincident with the depths at which hydrocarbon production and water-flood (secondary recovery) operations are conducted. Comparison of the historic earthquake activity with water-flood data shows that there was a possible increase in the number of large earthquakes ($M > 3.0$) in the mid-1960s when the number of water-flood projects and their injection pressures increased. The first felt event occurred in 1966. This tentative correlation suggests that the earthquakes are related to hydrocarbon production in this area.

● **2.4-14** Real, C. R., Toppozada, T. R. and Parke, D. L., **Earthquake catalog of California, January 1, 1900-December 31, 1974,** *Special Publication* 52, California Div. of Mines and Geology, Sacramento, 1978, 15 pp. and 10 microfiche.

The Earthquake Catalog Program is in three phases. During phase one, accounts were compiled of the larger pre-instrumental earthquakes and all instrumentally recorded events. At this stage, principal sources of information were identified, an inventory of references was compiled, and some preliminary historical research was conducted. A prototype database management system was developed and implemented. During phase two, data from felt reports were analyzed to improve epicenter locations and to assign magnitudes to pre-instrumental earthquakes that occurred from 1900 to 1932. Intensity data were collected and interpreted, and locations and magnitude assignments were revised. Phase two also included the merging of the post-1931 earthquake data. Phase three, the research and compilation of the pre-1900 earthquake data, began in early 1978 and will continue for at least two years.

Owing to the continuously evolving nature of the catalog data file, and the increasing demand for a comprehensive catalog of earthquakes for research and seismic hazard assessment, the California Div. of Mines and Geology (CDMG) is releasing this information as a series of

● *See* ***Preface****, page v, for availability of publications marked with dot.*

catalog editions. Each new edition extends the period of coverage further back as well as forward in time, as new information becomes available. Editions of the catalog will be released on a more or less annual basis and will be available in two forms: a magnetic tape file and a microfiche file. The entire catalog will not be published in paper form because most of the data on earthquakes since 1932 is already available in that form from the primary sources. Because the CDMG is a primary data source for catalog information before 1932, however, these early data have been published in paper form. The earthquake catalog is presented in four files on microfiche: (1) a chronologic file of all earthquakes; (2) a chronologic file of earthquakes equal to or greater than magnitude 5.0; (3) a chronologic file of earthquakes equal to or greater than magnitude 6.0; and (4) a file of all earthquakes, sorted by region.

● **2.4-15** Eguchi, R. T. and Hasselman, T. K., **A Bayesian seismic risk study of California,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 52-61.

This paper summarizes a study in which the seismic hazard of California is evaluated using Bayesian statistical theory. Seismotectonic and geologic data are combined with local historic seismicity data; the result is a composite estimate of seismicity, consistent with the relative degrees of confidence in each set of data. In addition, a Bayesian-like approach is used to integrate and incorporate variation in existing attenuation relationships for peak ground acceleration, velocity, and displacement. The results are displayed in the form of contour maps showing peak ground accelerations, velocities, and displacements as a function of return period. The analyses, completed under a U.S. Geological Survey-sponsored project, are part of an overall study to evaluate the potential economic effects of earthquakes on various categories of structures for California.

● **2.4-16** Gurpinar, A. et al., **Seismic risk analysis of northern Anatolia based on intensity attenuation,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 72-81.

Employed in this risk study are relationships between magnitude and frequency; maximum intensity and magnitude; maximum intensity, intensity, and distance; and magnitude and fault rupture length. In addition to the relationships, the generally accepted Poisson model for the occurrence of earthquakes is used. The results indicate that reliable seismic values can be obtained only through the use of region-dependent attenuation relationships.

● **2.4-17** Fischer, J. A., **Variability of earthquake hazard assessments in the eastern U.S.,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 109-116.

● **2.4-18** Katayama, T., **Seismic risk analysis in terms of acceleration response spectra,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 117-126.

A method for evaluating seismic risk in terms of the acceleration response spectrum is described. Similar efforts have been made in recent years; however, the method and data used in this paper are different from those used by previous investigators. The advantages of the method are demonstrated by several illustrative examples and the method is employed to obtain the seismic risk distribution for Japan.

● **2.4-19** Monzon-Despang, H., **Seismic performance of spatially distributed engineering systems—a numerical algorithm,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 653-662.

This paper presents a procedure for achieving a quantitative assessment of the seismic performance of systems spatially distributed with respect to a seismic environment. The procedure, based on Monte Carlo simulation methods, comprises three main steps: modeling of system damaged states; system analysis of the damaged states; and probabilistic analysis of system performance. The main objective is to keep the damage modeling and the probabilistic analysis independent of the specific system analysis needed to assess the performance under damaged conditions. This segregation is possible because the algorithm is not devised in an analytical closed-form solution. The approach has two advantages: first, the specialist in the system under consideration, who is not necessarily an expert in earthquake engineering or in probabilistic analysis, can more freely devise the required system response model; and, second, a standardized computer code can be devised for which the system-analysis routine can be simply changed to solve different problems.

● **2.4-20** Oliveira, C. S., **Comparative seismic hazard studies for the San Francisco Bay region,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 62-71.

In the San Francisco Bay area, the historical record of seismicity (about 170 years) is not long enough to permit either acceptance or rejection, with a minimum level of confidence, of the Poisson model of severe earthquake occurrence. To simulate interoccurrence times, however, the gamma probability model can be used. Extrapolations

● *See **Preface,** page v, for availability of publications marked with dot.*

for zones with very low risks ($< 10^{-3}$) can only be made based upon an evaluation of geotectonic evolution. Uncertainties in the limitation of source areas, source-mechanism and wave-attenuation formulas, and mathematical models are most critical for the evaluation of final distributions.

● **2.4-21** Savy, J. B., **Determination of seismic design parameters: a stochastic approach,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 723–732.

In recent years, most practicing engineers have used the Poisson model of earthquake occurrences. This procedure, although mathematically simple, has basic shortcomings. For instance, the memoryless Poisson model predicts that the day following the 1906 San Francisco earthquake would have the same likelihood of recurrence as a day in 1977. This does not reflect the source mechanism observed in the northern part of the San Andreas fault, for example, although it does model reasonably well some other source mechanisms in California.

It is proposed in this paper that a distribution of earthquake recurrence which takes into account the apparent time-dependency characteristics be chosen for seismic-risk analysis. Chou and Fisher suggested a Weibull distribution of the inter-arrival time. The Weibull distribution was first introduced in evaluating strength of materials and has since been used extensively in reliability studies and failure analysis. In the dislocation source model, the use of the Weibull distribution is consistent with the idea of failure of a mechanical component. The use of the Weibull distribution corresponds to selecting a nonstationary Poisson process model of occurrences. This selection reflects the knowledge that the failure rate of a fault that is locked after each major event increases with time.

● **2.4-22** Askins, R. C. and Cornell, C. A., **SHA-based attenuation model parameter estimation,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 703–712.

This paper presents the initial results of a new method for the fitting of semi-empirical strong-motion attenuation laws. The new feature is the explicit coupling of the attenuation law parameter estimation to the seismic hazard analysis. A weighted regression analysis is used in which the weights are proportional to the integrand of the integral which defines the contributions to the total probability of exceeding a given acceleration level.

● **2.4-23** Grandori, E., Grandori, G. and Petrini, V., **A discussion of "non-linear" magnitude-frequency laws,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1124–1133.

2.4-24 Hasegawa, H. S., Chou, C. W. and Basham, P. W., **Seismotectonics of the Beaufort Sea,** *Canadian Journal of Earth Sciences,* **16**, *4*, Apr. 1979, 816–830.

In this study, earthquake data were used in conjunction with bathymetry and gravity measurements to study the seismotectonics of the Beaufort Sea area. The epicenter cluster in the Beaufort Sea is confined to the continental slope between the 200 and 2400 m bathymetry contours and falls between the seaward -20 mGal and the landward +40 mGal contours of an elliptically shaped free-air gravity anomaly. The cluster, which experiences an average of one earthquake magnitude ≥ 4 per year, is shown by epicenter relocation studies to be a distinct zone and not the result of mislocations of earthquakes originating from a spatially confined source. Theoretical calculations of the stress field under the region where the gravity anomaly is most pronounced show that the horizontal component of the stress field is deviatoric tension normal to the axis of the continental margin; focal parameters of the June 14, 1975, m_b 5.1, M_S 4.2 Beaufort Sea earthquake indicate deviatoric tension in the same (east-west) direction at a depth of 40 km. The relatively small surface waves from this and other Beaufort Sea earthquakes, compared to other on-shore Arctic earthquakes, are probably caused by this deeper focus at the continental margin. The horizontal component of the deviatoric compression of this earthquake is north-south; a horizontal compressive stress from the north may be transmitted through the Arctic Ocean lithosphere from the Nansen-Gakkel spreading ridge. It is suggested that these stresses are acting on localized zones of weakness.

● **2.4-25** Bath, M. and Duda, S. J., **Some aspects of global seismicity,** *Report 1-79,* Seismological Inst., Uppsala Univ., Uppsala, Sweden, 1979, 41.

This catalog of major earthquakes occurring from 1965 to 1977 is a continuation of an earlier catalog covering the period from 1897 to 1964. Because the material is fairly homogeneous, it is evaluated with regard to some of its statistical properties, such as relationships of frequency and energy to magnitude and time.

● **2.4-26** Toppozada, T. R., Parke, D. L. and Higgins, C. T., **Seismicity of California, 1900–1931,** *Special Report 135,* California Div. of Mines and Geology, Sacramento, 1978, 39.

Basic data are presented in this report for the 517 earthquakes of magnitude 4 and greater or intensity V and greater known to have occurred from 1900 through 1931 within California and a 100 km zone surrounding the state.

● *See **Preface**, page v, for availability of publications marked with dot.*

Released for the first time in this report are estimates of 261 epicenter locations, 168 values of magnitude, 67 values of maximum reported intensity, and the approximate sizes of 61 areas of perceptibility. These estimates are based mainly on reported earthquake effects.

The only event of magnitude 8 or greater since 1900 was the San Francisco earthquake of 1906. Between 1900 and 1931, three other events had magnitudes of 7 or greater, and 24 events had magnitudes of 6 or greater. The most seismically active part of the state from 1900 through 1931 was along the southern and central San Andreas fault system. Strong earthquakes occurred in the Cape Mendocino area, and a broad zone of seismicity extended inland from the Cape to Nevada between latitudes 39° N and 41° N. A zone of seismicity bounded the eastern front of the Sierra Nevada, and earthquakes also occurred within the Sierra block. The least seismically active portions of the state between 1900 and 1931 were the Great Valley south of latitude 39° N and the eastern part of the Mojave Desert near the Colorado River.

● 2.4-27 Lomnitz-Adler, J. and Lomnitz, C., **A modified form of the Gutenberg-Richter magnitude-frequency relation,** *Bulletin of the Seismological Society of America,* **69,** *4,* Aug. 1979, 1209–1214.

A stochastic model of strain accumulation and release at plate boundaries is proposed. The model leads to the generalized Gutenberg-Richter relation ln $G(x)$ = constant - $B\exp(\alpha x)$, where G is the cumulative exceedence of a magnitude x. This relation tends asymptotically to the original Gutenberg-Richter relation in the low-magnitude range; at high magnitudes, the relation provides estimates of the probability of occurrence which are significantly more realistic than the Gutenberg-Richter relation. Excellent agreement is obtained with the data of the Chinese earthquake catalog covering a time period of 2753 years.

● 2.4-28 DuBois, S. M. and Wilson, F. W., **A revised and augmented list of earthquake intensities for Kansas, 1867–1977,** Kansas Geological Survey, Univ. of Kansas, Lawrence, Aug. 1978, 56.

Twenty-five earthquakes with epicenters in Kansas have been reported during the last 110 yr. Two large nuclear and coal-fired electrical generating complexes and several existing or proposed reservoirs are sited near or in areas of past seismic activity in Kansas. The seismic design parameters for these facilities are based largely upon the locations, sizes, and frequency of earthquakes which have occurred in the region as far back as reports are available. Because estimation of seismic risk is critical in these situations, it is important that the date, location, and size of each earthquake be determined as accurately as possible. The original purpose of this study was to verify the basis for placement of the 1867 and 1906 earthquake epicenters near Manhattan, Kansas. This objective was subsequently expanded to review the reports of all earthquakes with epicenters in Kansas. The investigation included a review of the references cited for Kansas earthquakes by authors of previously published state, regional, and national earthquake listings. In addition, old newspaper files, microfilms, and other records at the Univ. of Kansas and the Kansas State Historical Society were searched for reports which may have been previously overlooked. As a result of this study, three changes in epicenter locations and changes in modified Mercalli intensities for five earthquakes were made. This report includes a complete list of all felt reports compiled during this study.

● 2.4-29 McGuire, R. K., **FRISK: computer program for seismic risk analysis using faults as earthquake sources,** *Open-File Report 78-1007,* U.S. Geological Survey, 1978, 71.

This computer program calculates the probabilistic seismic hazard at sites affected by earthquakes occurring on faults defined by the user as a series of line segments. The rupture length of the fault as a function of earthquake magnitude is accounted for, and ground motion estimates at the site are made using the magnitude of the earthquake and the closest distance from the site to the rupture zone. Uncertainty regarding the earthquake magnitude, the rupture given the magnitude, the location of the rupture zone on the fault, the maximum possible magnitude of earthquakes, and the ground motion at the site are accounted for explicitly. FRISK (Fault RISK) was written to take advantage of repeated calculations so that seismic hazard analyses for several ground motion parameters (for instance, peak ground acceleration, velocity, and displacement) and for several sites may be made efficiently with one execution of the program rather than with repeated executions.

● 2.4-30 Racine, D. et al., **A seismicity study of the Pacific Northwest region of the United States, November 1961–August 1965,** Teledyne Geotech, Alexandria, Virginia, July 1979, 53.

This report is a seismicity study of the Pacific Northwest region of the United States for the period between Nov. 1961 and Aug. 1965. During the study, 326 epicenters (SDL events) were located by visual analysis of film records of short-period seismic data. Magnitudes for these events ranged from 1.5 to 4.2 and were computed with a method that utilized vertical component L_g motion. This method was shown to be compatible with body-wave magnitudes. These SDL events were in addition to the 302 events in the area of interest, ranging in body-wave magnitude from 3.0 to 6.5, which were compiled from the National Earthquake Information Service (NEIS) epicenter list. A plot of the 326 events shows the same general geographic distribution as the plot of the NEIS events, except in Oregon where most of the SDL events were located in the historically quiet SE

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

quadrant of the state. Considerably more events were located in Washington and Oregon than appeared on the NEIS plot, suggesting that the area of interest is far more active than traditionally thought. It is recommended in this report that the Corps of Engineers refine locations, develop single-station location techniques, develop travel-time tables for the region, and investigate depth determinations.

● **2.4-31** UNESCO (United Nations Educational, Scientific and Cultural Organization), **Annual summary of information on natural disasters: earthquakes, tsunamis, volcanic eruptions, landslides, avalanches—1975** (in English and French), *10,* Paris, 1979, 104.

The information about earthquakes given in this series of annual summaries of disasters includes sources of data, classification by seismo-tectonic region, compilation of regional tables, determination of magnitude, and epicentral maps. The epicenters of several thousand earthquakes are determined each year by the international and national seismological services. The 559 earthquakes selected as representative of the seismic activity in 1975 include the 136 whose magnitude was equal to or greater than 6. The parameters of these representative earthquakes, including their epicentral coordinates, focal depths, origin times, and magnitudes, are given in tabular form. The tables also include some earthquakes of lower magnitude whose locations are of interest either because they are unusual or because they help to delimit more accurately the seismic zones which mark the boundaries of the tectonic plates.

● **2.4-32** Pulpan, H. and Kienle, F., **Western Gulf of Alaska seismic risk,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3612, 1979, 2209-2218.

Seismicity studies, based on historic data and data accumulated from the operation of a high-resolution seismic network, provide important information for quantitative seismic risk studies for areas of offshore petroleum development in Lower Cook Inlet, Shelikof Strait, and off Kodiak Island. The greatest seismic risk is associated with the shallow seismic thrust zone of the subducting Pacific plate. There is a high probability that a great ($M > 7.8$) earthquake will occur in the Shumagin gap within the functional lifetime of any potential petroleum development in that area. The relative sharpness of the transarc boundaries of the aftershock zones of great earthquakes in the Aleutians suggests that the shallow thrust zone is segmented into separate tectonic blocks which release accumulated strain independently. There is geologic and seismic evidence that one such boundary traverses the arc near the southern edge of Kodiak and separates the 1964 aftershock zone from the Shumagin gap. Additional segmentation may exist within the 1964 aftershock zone. Seismic risk appears lower in the other offshore areas that do not overlie the shallow subduction thrust zone, but is still primarily associated with the subduction process. The shallow crustal seismic activity (less than 50 km hypocentral depth) outside the subduction thrust zone does not correlate with the major known fault systems of the area, and is of a more diffuse nature.

● 2.4-33 Seno, T., **Pattern of intraplate seismicity in southwest Japan before and after great interplate earthquakes,** *Tectonophysics,* **57,** *2-4,* Aug. 20, 1979, 267-283.

A fairly complete set of data on intraplate seismicity in southwest Japan during the past 170 yr reveals that the seismicity before great interplate earthquakes along the Nankai trough is high over the land area adjacent to the rupture zones of the great interplate earthquakes, and that the seismicity after the interplate earthquakes is high in the marginal zones that border the preseismically active area. This change of seismicity distribution before and after great interplate earthquakes can be explained by the two modes of horizontal deformation in the continental-plate margin, that is, the contraction of the land area adjacent to the rupture zone of great interplate events before their occurrence and the blockwise extension of the area seaward at the time of these interplate shocks. One of the characteristic features of intraplate seismic energy release during historic times is that it is large in the narrow zones which border the land areas adjacent to the specific rupture zones of historic great interplate earthquakes. These zones must have been exposed to the shearing stress caused by the blockwise extension of the areas adjacent to the specific rupture zones at the time of interplate shocks. This may provide a reason for the large seismic energy release within these marginal zones in historic times.

Recent intraplate seismicity in southwestern Japan shows that intraplate earthquakes tend to cluster in the area adjacent to the expected rupture zone of a future great event off the Tokai district. A simple statistical test shows that this clustering of intraplate events in the area is significant within a 96% confidence level. The level of seismic activity in this area is 18 times larger than the normal level of activity between interplate earthquakes. This high level of activity provides more evidence for the possibility of occurrence of a great interplate event off Tokai. The land area adjacent to the rupture zone off Tokai deserves high priority for instrumentation of various types to record in the near field the destructive intraplate earthquakes which may occur over several decades before and after the future great Tokai event.

● 2.4-34 Bath, M., **Seismic risk in Fennoscandia,** *Tectonophysics,* **57,** *2-4,* Aug. 20, 1979, 285-295.

Seismic risk is calculated by means of recurrence periods obtained from least-squares relations between the number and magnitudes of earthquakes. This method is

● *See **Preface,** page v, for availability of publications marked with dot.*

described and applied to Fennoscandia. The results, summarized in tabular form, give the seismic risk for 54 regions, each comprising 2° in latitude and 2° in longitude, and for the magnitude range from 2.0 to 5.0 on the regional scale.

● 2.4-35 Wilson, F. W., **A study of the regional tectonics and seismicity of eastern Kansas-summary of project activities and results to the end of the second year, or September 30, 1978,** *NUREG/CR-0666,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Mar. 1979, 69.

The Kansas Geological Survey, in cooperation with the State Geological Surveys of Oklahoma, Nebraska and Iowa, is making a five-year study of the regional tectonics and seismicity of the Nemaha uplift, an area of moderate historical seismicity, and related geologic structures in order to better understand the sources and mechanisms of the seismic activity in the central midcontinent. The studies are intended to provide a more rational evaluation of earthquake risk as it applies to the design of nuclear facilities. This report summarizes the progress of all research done in Kansas during the first two years of the project and details the results and preliminary conclusions of the research.

● 2.4-36 Weichert, D. H. and Milne, W. G., **On Canadian methodologies of probabilistic seismic risk estimation,** *Bulletin of the Seismological Society of America,* **69,** 5, Oct. 1979, 1549-1566.

Three probabilistic methods for the estimation of seismic risk have been used in Canada. A reevaluation of the extreme value method shows no advantages over the average value method of Milne and Davenport. Conceptual improvements in the underlying assumptions of the latter method are a constrained release of historical earthquakes from their presumed epicenters and the averaging of earthquake rates over variable periods. Risk estimation can then proceed as suggested by Cornell. Comparison of the results of this modification of the average number method shows similar results to the Milne and Davenport average value method. The stability of risk estimates against new earthquakes is improved, but sensitivities at typical sites toward unavoidable deterministic elements in the model are similar to the older method. For certain site-source-seismicity combinations, probabilistic estimates of ground motion could become almost quasi-deterministic.

● 2.4-37 Basham, P. W., Weichert, D. H. and Berry, M. J., **Regional assessment of seismic risk in eastern Canada,** *Bulletin of the Seismological Society of America,* **69,** 5, Oct. 1979, 1567-1602.

Earthquake recurrence data for eastern Canada are used to derive estimates of probabilistic seismic risk at the low levels desirable for critical structures. Historical earthquake data from 1661 to 1975 are employed to produce a seismicity model consisting of six zones of earthquake occurrence in the continental region and an isolated zone on the Grand Banks. Magnitude recurrence relations are derived for each of the zones. Seismic risk estimates (probability of peak ground acceleration being exceeded) are derived using the Cornell method of integrating risk contributions from the zones of earthquake occurrence. For sites within the larger zones of relatively low seismicity, e.g., the Northern Appalachian Zone, with little influence from adjacent zones, the risk estimates near 10^{-3} per annum are relatively insensitive to the uncertainties in the magnitude recurrence parameters; the maximum risk contribution comes from the lower magnitude earthquakes at the near distances. For sites within the range of influence of highly active areas, such as the Charlevoix Zone, peak ground motions with a risk of being exceeded near 10^{-3} per annum can vary by a factor of two depending on assumptions of the magnitude recurrence extrapolation and the maximum magnitudes. Constraints on the seismicity based on tentative geological correlations increase ground motion for sites near some active zones by factors of up to 1.5 at the same risk level compared to that derived from the model based only on historical earthquake distributions.

With the present knowledge of tectonic processes in eastern Canada, the uncertainties in magnitude recurrence extrapolations and maximum magnitudes, the assumptions about the temporal and spatial stationarity of earthquake zones, and the uncertainties on near-field effects and attenuation, seismic risk estimation at probabilities below 10^{-3} per annum becomes increasingly deterministic.

● 2.4-38 Katayama, T., **Seismic risk as expressed by acceleration response of single-degree-of-freedom system,** *Bulletin of Earthquake Resistant Structure Research Center,* **12,** Mar. 1979, 15-23.

The feasibility of seismic risk analysis in terms of acceleration response spectra is examined by use of several example calculations. The results of the statistical analysis of 277 acceleration response spectra are used as the attenuation law. The seismic risk thus evaluated is found to more clearly show the seismic environment of a site with respect to earthquake engineering purposes than the ordinary seismic risk determined in terms of peak amplitude of ground motion. The preliminary analysis indicates that the seismic risk to long-period structures is more uniformly distributed over the whole area of Japan than that to short-period structures.

● 2.4-39 Glass, C. E. and Slemmons, D. B., **Imagery in earthquake analysis,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report*

● *See **Preface**, page v, for availability of publications marked with dot.*

11, Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Dec. 1978, 233.

Recent advances in the fields of remote sensing, engineering geology, seismology, and earthquake engineering have created a need for a systematic comprehensive review of the basic principles and methods of applying remote sensing to the evaluation of earthquake hazards and seismic risk. This paper reviews basic concepts, summarizes essential, state-of-the-art knowledge of theory and instrumental methods, establishes procedures evaluations, and discusses representative case histories that illustrate earthquake hazard evaluations based on remote sensing analysis. The recommended approach is based on a multi-faceted approach that uses an integrated and systematic study of a region or a fault with a variety of imagery varying from small-scale (synoptic) to large-scale (detailed). The imagery analysis should be followed by a ground verification program of study that ought to include both ground and aerial reconnaissance examinations of the major geologic structures of concern. The character of the earthquake hazards is discussed in the context of the lithologic, structural, vegetational, and topographic variations that are associated with different types of active geologic structures. The response of earth materials, landforms, and geologic structures is summarized for the several main types of passive and active electromagnetic radiation used in current remote-sensing practice. The limitations of the different spectral regions used in remote sensing are reviewed to assist in the selection of ideal methods of study for effective evaluation of active or capable faults and to assess the earthquake potential of geologic structures that may affect a given engineering site. The case histories provide examples of representative problems, approaches, sequences of study, and methods of estimating the activity or inactivity of faults. These studies were based on lineament analysis, estimating earthquake magnitudes that could be associated with future faulting along active faults, or determining fault lengths, zone widths, and maximum expected surface displacement or separations.

● **2.4-40** Eiby, G. A., **Principal New Zealand earthquakes in 1978,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, p. 66.

No major earthquakes occurred in the New Zealand region during 1978, making that year and 1977 two of the quietest years since modern recording instruments were first installed in the 1930s. There was no significant damage, and only two shocks were felt over wide areas. None of the shocks reached a magnitude of 6, and there was less than half the usual number of shocks reaching magnitude 5. The Seismological Observatory located and assigned magnitudes to some 700 small events, about 300 less than in a normal year. Several of the events are described in this paper.

● **2.4-41** Luza, K. V. et al., **Seismicity and tectonic relationships of the Nemaha uplift in Oklahoma,** *NUREG/CR-0050,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Apr. 1978, 69.

Geologic and seismologic investigations of the Nemaha uplift began on Oct. 1, 1976. The geological studies have focused, thus far, on the construction of a series of structure-contour maps on key stratigraphic horizons: the top of the Viola Formation, the base of the Pennsylvanian, and the top of the Oswego Formation. The contour-mapping phase of the program is approximately two-thirds completed. The initial mapping program reveals the complex fault pattern and geologic history of the Nemaha ridge. It appears that the uplift and associated faults began in Early Pennsylvanian time and that tectonic activity ceased in Middle Pennsylvanian time, at least in central Oklahoma. A discussion of basement rocks in central Oklahoma is included in this report. The most systematic basement-rock study that includes the Nemaha ridge area was done by Denison (1966), who classified the central Oklahoma basement rocks into the following four units: (1) Washington County Volcanic Group, (2) Spavinaw Granite Group, (3) Osage County Microgranite, and (4) Central Oklahoma Granite Group. The isotopic ages range from 1150 to 1270 million yr, and these ages, when considered with analytical variations, indicate a main period of thermal activity about 1200 million yr ago.

The seismological studies have concentrated on the installation of eight seismometers which permit detailed coverage of the entire Nemaha ridge as well as most of the remaining area of Oklahoma. Five stations are now in full operation. Because maintenance problems have been particularly severe with the MEQ-800 clock, the remaining three clocks are used as back-up units until the problem is solved. Work has begun on the installation of three high-frequency vertical seismometers linked by radio to the observatory for extended directional capability. While studying the theory and practice of VHF radio links, it was discovered that an installation could be located 50 to 80 km from the observatory. It was then decided that the radio links would be spaced to serve as additional network stations rather than simply to confer directional capability. One radio link, 76 km northeast of the observatory, is in operation.

A HP-9825A programmable calculator and a 9866B line printer were installed at the Univ. of Oklahoma Earth Sciences Observatory. Six computer programs were developed for storage and processing of all teleseismic and local arrival-time and amplitude data. A program is being developed to produce an earthquake bulletin for the study area which includes Oklahoma, Kansas, and Nebraska. A catalog of all known Oklahoma earthquakes was prepared. No earthquake prior to 1908 has been documented; however,

● *See **Preface**, page v, for availability of publications marked with dot.*

the literature is still being searched for historical seismic events. See Abstract No. 2.4-42 for the progress of the investigation described in this report.

● 2.4-42 Luza, K. V. and Lawson, J. E., **Seismicity and tectonic relationships of the Nemaha uplift in Oklahoma; part II,** *NUREG/CR-0875,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1979, 81.

This report describes the continuation of the investigation discussed in Abstract No. 2.4-41. The contour-mapping phase of the program was completed in 1978, but the maps are not yet in final form. A detailed study of the tectonics of the Oklahoma City uplift involved the construction of four subsurface cross sections as well as several isopach maps in order to reconstruct the structural history of this area.

● 2.4-43 Ozaydin, K. and Erguvanli, A., **Seismicity of the North Anatolian fault, Turkey,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 40, 14.

The seismicity of the North Anatolian fault has been assessed by means of the statistical Gutenberg-Richter relationship and the stochastic Gumbel distribution, using earthquake data for the past 65 years. The Gutenberg-Richter parameters are shown to be related to the constants defining the Gumbel distribution. Based on this relationship, it is concluded that the Gumbel distribution for large earthquakes, which is of more significance for the assessment of the seismicity of a site, can easily be obtained from the parameters defining the Gutenberg-Richter relationship.

● 2.4-44 Krinitzsky, E. L., **Geological-seismological factors for specifying motions in the design of future dams in Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 56, 25.

Future dams in Guatemala may very likely be located on or adjacent to active faults that are capable of generating maximum earthquakes. Geological investigations of sites should provide data on displacements that might occur under a structure and on landslides that might cause waves in a reservoir. Possible induced seismicity from reservoir loading is not predictable but is not likely to be of importance for design. The rate of earthquake recurrence is not a problem where a maximum earthquake is specified. However, appurtenant structures may be designed on a cost-risk basis involving recurrence. Peak motions for a maximum earthquake can be specified from relationships between MM intensity and acceleration, velocity, displacement, and duration developed from available strong-motion records. Time histories of earthquake motion can then be made by rescaling existing records or generating synthetic ones.

● 2.4-45 Terashima, T. and Yokota, T., **The map of historical earthquakes along or nearby active faults in Japan—purporting to basic materials for earthquake prediction** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* 32, *1,* Mar. 1979, 1-10.

Active faults are considered to be surficial expressions of shallow earthquake generation. If this is true, an active fault along which no shallow earthquakes have been observed is thought to be dangerous with a high possibility of storing enough stress in the near future to generate a large shallow earthquake with a long recurrent period. Based upon this concept, the authors attempted to clarify the characteristics of such faults by superimposing the locations and sizes of historical earthquakes on an active fault map completed for all Japan except the area of Hokkaido. The authors recommend that geophysical and geological studies be made of these active faults.

● 2.4-46 Yegian, M. K., **Probabilistic seismic hazard analysis,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 13,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, July 1979, 132.

This report presents a comprehensive review of the state-of-the-art of probabilistic seismic hazard analysis. This type of analysis essentially provides information on the likelihood that various levels of a ground motion parameter will be exceeded in a given period of time. The report begins with a discussion of the various seismic parameters required for the analysis and calculation of these parameters based on seismic history data. Problems involved in the estimation of these parameters exclusively on the basis of seismological data are outlined, and emphasis is placed on the need to utilize and incorporate geologic and geophysical information in the analysis. A brief presentation of Bayes's theorem and a discussion of the procedure for seismic hazard estimation using the theorem are provided. Various mathematical formulations used in the calculation of seismic hazard probabilities are presented. The use of computer programs to facilitate the calculations involved in the analysis is discussed. Concluding the report is a discussion of the various practical applications of seismic hazard analysis, emphasizing its use in structural and geotechnical engineering. Some recent seismic hazard maps for the U.S. incorporating probability calculations are reviewed in this section.

● 2.4-47 Wilson, F. W., **Nemaha Uplift seismotectonic study: regional tectonics and seismicity of eastern Kansas,** *NUREG/CR-1144,* Div. of Reactor Safety Research, U.S.

● *See **Preface,** page v, for availability of publications marked with dot.*

Nuclear Regulatory Commission, Washington, D.C., Nov. 1979, 18.

Progress and results of the first two years' work on this project were reported in NUREG/CR-0666, published in Mar. 1979 (see Abstract No. 2.4-35 in this volume of the *AJEE*). Activities and results of the project's third year were as follows: (1) continued operation of a regional microearthquake monitoring network which detected and located 26 regional events between Oct. 1, 1978, and Aug. 2, 1979; (2) designing and building a triggering system to allow digitized recording of microearthquakes by a modified exploration seismograph; (3) continued surface and subsurface studies of selected areas along the Nemaha Uplift–Keweenanan Mafic belt trend; (4) continued study of Precambrian rock types from recently drilled wells; (5) beginning compilation of a fault catalog; (6) terrain analysis and lineament studies which indicate that the alignment of stream drainages and divides are strongly controlled by basement and subsurface structure; (7) continued reduction of gravity data for northeastern Kansas (a Bouguer gravity map probably will be available in late Fall 1979); (8) modification of the exploration seismograph system to a more efficient 12-channel Mini-Sosie system and completion of several line-miles of reflection profiling; and (9) beginning integration of data from Oklahoma, Nebraska, and Iowa coinvestigators.

● 2.4-48 Yucemen, M. S., **Source modelling and uncertainty analysis in the evaluation of seismic risk for nuclear power plants**, Dept. of Applied Statistics, Middle East Technical Univ., Ankara, Nov. 1978, 164.

Probabilistic and statistical methods are used to develop a procedure by which the seismic risk at a specific site can be systematically analyzed. The proposed probabilistic procedure provides a consistent method for the modeling, analysis, and updating of uncertainties that are involved in the seismic risk analysis for nuclear power plants. Methods are proposed for including these uncertainties in the final value of calculated risks. The potential earthquake activity zones are idealized as point, line or area sources. For these seismic source types, expressions to evaluate their contribution to seismic risk are derived, considering all the possible site-source configurations.

The seismic risk at a site is found to depend not only on the inherent randomness of the earthquake occurrences with respect to magnitude, time, and space, but also on the uncertainties associated with the predicted values of the seismic and geometric parameters, as well as the uncertainty in the attenuation model. Thus, a full probabilistic approach, leading to a realistic estimate of the seismic risk for a given site, should also account for the uncertainties associated with the assumed relationships and the input parameters. The uncertainty due to the attenuation equation is incorporated into the analysis through the use of random correction factors. The influence of the uncertainty resulting from the insufficient information on the seismic parameters and source geometry is introduced into the analysis by computing a mean risk curve averaged over the various alternative assumptions on the parameters and source geometry. The Bayesian probabilistic approach is used to combine various sources of information with statistical data to obtain the best estimates of the seismic parameters and the accompanying uncertainties.

Two specific case studies are presented in detail to illustrate the application of the probabilistic method of seismic risk evaluation and to investigate the sensitivity of results to different assumptions. In the first case, a seismic risk analysis is conducted for the city of Denizli, which is located in the most seismically active zone of Turkey. The second analysis is for Akkuyu, which is being considered as the location for the first nuclear power plant to be built in Turkey. The input data used in these case studies is based mainly on historical data, and no detailed geologic or tectonic studies of the sites were carried. Thus, the results cannot be used in the selection of final design values, unless the data used in these analyses are justified through further geologic and tectonic studies of the regions under consideration. An empirical peak acceleration-risk curve based on observed data is obtained for Denizli. The curve is compared with the risk estimates computed from the probabilistic model presented in this study. The theoretical predictions are found to agree reasonably well with the observed values for the range for which historical data is available. In the case study for Akkuyu, the selection of the design acceleration levels for nuclear power plants is also discussed.

● 2.4-49 Bollinger, G. A. and Stover, C. W., **List of intensities, epicentral distances, and azimuths for the 1897 Giles County, Virginia, earthquake and the 1969 Elgood, West Virginia, earthquake**, *Open-File Report 78-1017*, U.S. Geological Survey, 1978, 17.

This listing provides the epicentral distances and azimuths to intensity-reporting localities for two earthquakes important to the seismicity of the southeastern United States. The 1897 Giles County, Virginia, shock is the largest historic event to have occurred in that state. The 1969 Elgood, West Virginia, earthquake represents the largest recent shock from the same locale. Thus, in terms of the amount of seismic energy released as well as the amount of intensity information available, these two earthquakes represent the best data set for the southern Appalachians. For the 1897 event, the epicenter was assumed to be at Pearisburg, Virginia (37.32°N, 80.73°W) while the epicenter employed for the 1969 West Virginia event was 37.4°N, 81.0°W. The listings are arranged alphabetically by state and by location. Latitudes and longitudes of intensity-reporting localities were scaled from appropriately sized maps, and epicentral distances and azimuths

● *See* ***Preface****, page v, for availability of publications marked with dot.*

were computed by conventional formulas. For both shocks, the two published assignments of individual modified Mercalli intensities are given in the listings.

● 2.4-50 Mauk, F. J. et al., **Geophysical investigations of the Anna, Ohio earthquake zone—Annual progress report: July 1978-July 1979,** *NUREG/CR-1065,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Oct. 1979, 182.

During fiscal year 1979, the Anna seismic array of nine local stations and two remote stations has continuously collected seismic data from the Anna, Ohio, seismic zone. Seismic records of local quarry blasts have been used to measure the velocity of Lg surface waves in west-central Ohio. An experimental technique using moving window analysis of quarry blast records has yielded significant data on the crustal structure in the region. In addition, considerable effort has been devoted to software development and acquisition. Data on bedrock depth has been collected from well log information in order to improve maps of the buried Teays River Valley, which may be related to proposed faults in the area.

● 2.4-51 Van Eck, O. J. et al., **Regional tectonics and seismicity of southwestern Iowa—Annual report: May 1, 1978-April 30, 1979,** *NUREG/CR-0955,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., 1979, 24.

The Iowa Geological Survey in cooperation with the State Geological Surveys of Kansas, Nebraska, and Oklahoma, is making a five-year study of the Midcontinent Geophysical Anomaly and the Nemaha Uplift. The intent is to gain a better understanding of the sources and mechanisms of the earthquakes that have occurred in the region. The various studies are designed to provide information that will permit more meaningful evaluation of earthquake risk factors in the siting and design of nuclear facilities. This report summarizes the progress of all research done in Iowa during the first year of the project and details the results and preliminary conclusions.

● 2.4-52 Toppozada, T. R., Real, C. R. and Pierzinski, D. C., **Seismicity of California: January 1975 through March 1979,** *California Geology,* 32, 7, July 1979, 139–142.

● 2.4-53 Blum, E., Lara, O. and Palacio, J., **Justification and methodology for a seismic risk study for Ecuador** (Justificacion y metodologia de un estudio de riesgo sismico para el Ecuador, in Spanish), *IIEA Report 79-01,* Univ. de Guayaquil, Ecuador, 1979, 90.

This report presents a discussion of the different scientific disciplines involved in a seismic risk study. The seismic history and seismic conditions in Ecuador that make a seismic risk study necessary are outlined. A methodology is suggested which considers the interrelationships among seismology, geology, and risk analysis in formulating a seismic-resistant design code for different regions in the country. The final chapter is devoted to instrumentation.

● 2.4-54 Kiremidjian, A. S. and Shah, H. C., **Seismic hazard analysis of Honduras,** *38,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Aug. 1979, 300.

The basic objectives of the project are to: (1) accumulate and compile the seismological and geological information about the seismic environment of Honduras; (2) based on the available information, develop a seismic source model for the country and obtain recurrence relationships with associated uncertainties for all sources; (3) based on the information developed in (2), determine a maximum credible event for the El Cajon region; (4) with proper development of an attentuation relationship, determine a seismic hazard map for the entire country of Honduras; and (5) develop acceleration zone graphs (PGA vs. return period) for major population centers as well as for various specific sites in the El Cajon region. This report presents the results of the project.

● 2.4-55 Coffman, J. L., **Earthquake history of the United States (1971-76 supplement),** *Publication 41-1,* U.S. Natl. Oceanic and Atmospheric Admin. and U.S. Geological Survey, Boulder, Colorado, 1979, 41.

This publication contains descriptions of earthquakes of modified Mercalli (MM) intensity V and above (intensity VI and above in California) for 1971 through 1976. It is a supplement to *Earthquake History of the United States (through 1970)* (Publication 41-1, rev. ed., Environmental Data Service, U.S. National Oceanic and and Atmospheric Admin., 1973). Although presented in essentially the same format as the 1973 edition, this supplement does not include the section, "Earthquake in the Various States." Another difference is that earthquake origin times are given in Coordinated Universal Time instead of local time. The data are grouped in the same geographical regions as before. In the section for each region, there are a brief summary of the general seismicity and tabular data on qualifying earthquakes in 1971–1976, followed by brief descriptions for each. The earthquakes are grouped into "major" and "intermediate and minor" categories. Isoseismal/intensity maps accompany those descriptions for earthquakes that were perceived by residents over extended distances (a minimum of about 20,000 sq km).

● 2.4-56 Guidi, G. A., **Computer programs for seismic hazard analysis—a user manual (Stanford seismic hazard analysis-STASHA),** *36,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Mar. 1979, 225.

● *See **Preface**, page v, for availability of publications marked with dot.*

This report describes an organized set of computer programs for use in performing seismic hazard analyses at specific geographic locations. The programs are based on probabilistic seismic risk models which have been used to map the seismic hazards of Nicaragua, Costa Rica, Guatemala, Algeria, offshore Alaska, California, and Honduras. Written in FORTRAN IV, the programs have been tested on the Stanford Univ. IBM 370/168 computer. Some of the programs, such as the plotting and mapping routines, are system-oriented and can be used only at the Stanford Computer Center.

● 2.4-57 Mortgat, C. P., Campbell, K. W. and Bernreuter, D. L., **Expert opinion encoding in seismic hazard analysis,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 3/4, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents general results of a survey of ten expert seismologists and geologists conducted as part of a Bayesian seismic hazard analysis of the northeastern United States. The survey, conducted by a written questionnaire, proved very useful in providing the most up-to-date information on Eastern seismotectonics within a limited budget and time frame. The questionnaire was composed of five sections: source zone configuration, maximum earthquakes, earthquake occurrence, attenuation, and overall level of confidence. The respondents were encouraged to answer in terms of probability distributions, but most responded with best estimates and ranges. It was found that a great deal of scatter prevailed among the responses of the experts. This posed an interesting problem with regard to forming a consensus of opinion. An example in terms of earthquake occurrence rates is presented to show the different methods and effects of combining the expert subjective information with historical earthquake occurrence data.

● 2.4-58 Grivas, D. A., Dyvik, R. and Howland, J., **An engineering analysis of the seismic history of New York State,** *Report CE-78-7,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Dec. 1978, 77.

The present study provides an engineering analysis of the seismic history of New York State. Available earthquake data have been compiled and analyzed. The resulting list contains 1289 seismic events that occurred between 1568 and 1975. The functional relationship between frequency and magnitude of earthquakes is investigated for a range of the magnitude m between 2.0 and 7.0 ($2.0 < m < 7.0$). This range of magnitude involves a total of 1242 seismic events. On the basis of the results of this study, it is concluded that a log-quadratic frequency-magnitude relationship best represents the available data. The seismic risk that corresponds to the log-quadratic frequency-magnitude relationship is determined for a number of time periods and under the assumption that earthquakes occur in accordance with the Poisson model. The case where earthquakes follow a more general Markov process is also investigated. In Appendix A is given the list of the analyzed seismic events sorted by date. A list with the same events, sorted by magnitude in 50-year periods, is given in Appendix B.

● 2.4-59 Solonenko, V. P., ed., **Seismic regionalization of Eastern Siberia and its geological and geophysical foundations,** *JPRS 74093, VAAP/SA-79/17,* Joint Publications Research Service, Arlington, Virginia, Aug. 1979, 428. (Translation of *Seysmicheskoye rayonirovaniye vostochnoy sibiri i ego geologo-geofizicheskiye osnovy* (in Russian), Izdatel'stvo Nauka, Novosibirsk, U.S.S.R., 1977.)

This report contains a description of the results of many years of complex seismogeological, seismic, and geophysical studies of Eastern Siberia aimed at establishing a basis for mapping its seismic regionalization. The genetic classification of the residual seismogenic deformations of the earth's crust and the fundamentals of the paleoseismogeological method—determination of the location and intensity of powerful earthquakes—are presented. A study is made of the problems of predicting earthquakes, the seismic regionalization, and the peculiarities of the manifestation of earthquakes under permafrost conditions.

● 2.4-60 Dart, R. L. et al., **Puerto Rico seismic program: seismological data summary, July 1, 1975 - December 31, 1977,** *Open File Report 79-870,* U.S. Geological Survey, Denver, Colorado, 1979, 138.

The purpose of this data summary is to compile and make available preliminary data acquired from a network of seismic stations in order to facilitate current studies of earthquake occurrence. Record interpretation, data processing, and collation of hypocentral data and related event parameters were performed by the U.S. Geological Survey in Golden, Colorado. The hypocentral solution data for the earthquakes and blasts that are listed, and hypocentral data for teleseisms and unsolved events that are not summarized in this report can be obtained on magnetic tape from the National Technical Information Service, Springfield, Virginia 22161. Accession No. PB 296 549-AS must be specified.

● 2.4-61 Kaul, M. K., **Use of fault displacements in the evaluation of seismic risk,** *Earthquake Engineering & Structural Dynamics,* 7, 6, Nov.-Dec. 1979, 529-542.

The need for a probabilistic description of earthquake magnitudes and their epicenters, specifically their joint probability density function, arises in the quantitative assessment of seismic risk. For line sources, this description has generally been assumed to be of a specific form, dictated primarily by the unavailability of relevant statistical data. The need for such simplification can, however, be eliminated if the available statistical data are supplemented by the knowledge of the accumulated displacements on the fault, thereby leading to an improved estimate of the required probability density function. A procedure to obtain such an improved estimate and simultaneously the mean occurrence rate of earthquakes originating from the fault is developed in this paper. The use of these refined inputs in seismic risk evaluation is described. Numerical examples are presented for illustration.

● **2.4-62** Qamar, A. and Hawley, B., **Seismic activity near the Three Forks Basin, Montana,** *Bulletin of the Seismological Society of America,* 69, 6, Dec. 1979, 1917–1929.

Most historical earthquakes near the Three Forks Basin, Montana, have been concentrated in the southwestern and northern portions of the basin and not along the spectacular escarpment of the Bridger Range fault which bounds the basin on the east. Relocation of earthquakes from 1974 to 1977 using earthquake data from regional seismograph networks and three microearthquake surveys (1974, 1976, and 1977) show that the most seismically active area is the Clarkston Valley, 10 km north of the Three Forks Basin. Reanalysis of travel-time data confirms Pardee's hypothesis that the large Montana earthquake of 1925 (magnitude 6 3/4) also occurred in Clarkston Valley. The seismologically determined focal mechanism for this earthquake differs from fault mechanisms of recent events in the valley.

● **2.4-63** Pereira, J. and Gay, D., **An engineering risk analysis for Jamaica and Trinidad,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 71–92. (For a full bibliographic citation, see Abstract No. 1.2–21.)

This paper constitutes an approach to the evaluation of seismic risk in terms of engineering ground motion parameters of acceleration and velocity in the Jamaica and Trinidad areas. In carrying out these evaluations, the following steps were observed: (1) examination of the tectonic environment thought to influence the seismic activity in these areas; (2) recalculation of the magnitude of events within the areas for which teleseismic data was available; (3) representation of fault zone activity in the form log n(M) = a - bM; and (4) the calculation of engineering seismic risk using the Cornell method of analysis. The paper is divided into two sections, Section A containing the analysis of the Jamaica zone and Section B that of the Trinidad zone. The paper concludes with a discussion of the limitations of such an approach.

● **2.4-64** Shepherd, J. B. and Aspinall, W. P., **Estimating earthquake risk in Jamaica,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 120–142. (For a full bibliographic citation, see Abstract No. 1.2–21.)

A review of the history of earthquake observations in Jamaica is presented and the observed seismicity of the Jamaica region is discussed in the context of regional tectonics. Possible source regions of Jamaican earthquakes are identified but a comparison between instrumentally determined seismicity and macroseismicity shows that the instrumental data are of insufficient quantity or quality to permit direct assessment of earthquake risk. A study of the macroseismic record suggests that the peak acceleration in rock with 90% probability of not being exceeded in any 50-year period is of the order of 0.3 g but that there are significant local variations caused by surface geology. A current apparent decline in the seismicity of the Jamaica region is noted but it is shown that the decline in the number of earthquakes of engineering interest is not yet statistically significant.

● **2.4-65** McDonald, F. J. and Turnovsky, J., **Physical development and associated seismic risk in Jamaica,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 93–109. (For a full bibliographic citation, see Abstract No. 1.2–21.)

This paper describes the seismic history of Jamaica and the present seismicity and risk in relation to the geology and tectonics of the area. The physical development of the area and related risk are discussed. The potential economic impact of a major event and matters associated with policies to reduce risk are described.

● **2.4-66** Bollinger, G. A. and Mathena, E., eds., **Seismicity of the Southeastern United States, January 1, 1979 - June 30, 1979,** *Southeastern U.S. Seismic Network Bulletin 4,* Dept. of Geological Sciences, Virginia Polytechnic Inst. and State Univ., Blacksburg, Nov. 1979, 80.

This report includes a tabular listing, by state, of the 79 stations operating during the period Jan.-June 1979. The format of the information included in the table is as follows: (1) three or four letter station code, (2) station latitude in decimal degrees, north, (3) station longitude in decimal degrees, west, (4) station elevation, meters, (5) geographic name of station, and (6) station operator. Geographic maps of the Southeastern United States Seismic Network and the South Carolina, Virginia, and Georgia networks are shown. An appendix gives general station information and magnification curves.

● **2.4-67** Taylor, L. O., Aspinall, W. and Morris, P., **Preliminary analysis of seismic risk in the Lesser Antilles and Trinidad and Tobago,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 143–177. (For a full bibliographic citation, see Abstract No. 1.2–21.)

This paper describes the results of an engineering analysis of seismic risk using the methods of Cornell for the area 8° - 20°N, 58° - 64°W. Earthquake source zones were

● *See **Preface**, page v, for availability of publications marked with dot.*

developed from a review of the tectonics and structure of the region and an analysis of strain release using the earthquake magnitude records for the period 1904-1974. The earthquake-magnitude frequency relationships were based on the latter records.

● 2.4-68 Valenzuela, L., **Seismic problems in Brazil,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 110-119. (For a full bibliographic citation, see Abstract No. 1.2-21.)

● 2.4-69 **Atlas on seismicity and volcanism,** Swiss Reinsurance Co., Zurich, 1978, 40.

● 2.4-70 Utsu, T., **Seismicity of Japan from 1885 through 1925—a new catalog of earthquakes of $M \geq 6$ felt in Japan and smaller earthquakes which caused damage in Japan** (in Japanese), *Bulletin of the Earthquake Research Institute, University of Tokyo,* **54,** *Part 2,* 1979, 253-308.

Since 1952, only one catalog has been available for moderate to large earthquakes occurring in the region of Japan from 1885 to 1925. However, the catalog, published by the Central Meteorological Observatory, has often been criticized as misleading because no consideration is given to the depth of focus and thus magnitude values are unreasonably large for many earthquakes. A new catalog of earthquakes of $M \geq 6$ is prepared in this paper to aid in the study of earthquake prediction and risk for Japan. Both instrumental and macroseismic data are used in the determination of focal parameters. Most of the data are taken either from published reports of the Central Meteorological Observatory, the Imperial Earthquake Investigation Committee, or written station reports collected and stored by the Japan Meteorological Agency and the Univ. of Tokyo. The hypocenter locations are mainly based on the *S-P* time intervals and the magnitude determinations are mostly a result of the maximum amplitude recorded by old-fashioned seismographs. For older events, the determination is more dependent on the seismic intensity distributions. The catalog lists 555 earthquakes of $M \geq 5.9$ and 53 destructive earthquakes of $M \leq 5.8$. The procedure for the focal parameter determination is explained in detail using six sample earthquakes. Referring to the epicentral maps constructed from this catalog, the author describes the characteristics of the seismicity of Japan from 1885-1925. A special description of 79 selected earthquakes of particular interest is given in the last half of the paper.

● 2.4-71 Tomblin, J., **Earthquake parameters for engineering design in the Caribbean,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 10-27. (For a full bibliographic citation, see Abstract No. 1.2-21.)

The seismological and geological data which serve as an input to earthquake hazard determination in the eastern Caribbean are reviewed, and a simple method is presented by which the data may be converted into peak ground acceleration values and plotted either graphically as a function of recurrence probability and distance from active sources, or as iso-acceleration contours on maps. The extent of possible errors is assessed.

● 2.4-72 Iaccarino, E. and Molin, D., **Macroseismic atlas for northeastern Italy from 0 A.D. to April 1976** (Atlante macrosismico dell'Italia Nordorientale dall'anno 0 all'aprile 1976, in Italian), *RT/DISP(78)8,* Comitato Nazionale Energia Nucleare, Rome, 1978, 118.

● 2.4-73 Molin, D., **Isoseismic maps of the Grottaminarda earthquake of July 24, 1977, the Apice earthquake of February 6, 1978, and the Matera earthquake of September 25, 1978** (Carte delle isosisme dei terremoti di Grottaminarda (24 luglio 1977), Apice (6 febbraio 1978) e Matera (25 settembre 1978), in Italian), *RT/AMB(79)3,* Comitato Nazionale Energia Nucleare, Rome, 1979, 7.

● 2.4-74 Magri, G. and Molin, D., **Macroseismic activity in Basilicata, Campania and Puglia from 1847 to 1861** (Attivita macrosismica in Basilicata, Campania e Puglia dal 1847 al 1861, in Italian), *RT/AMB(79)5,* Comitato Nazionale Energia Nucleare, Rome, 1979, 100.

● 2.4-75 Deacon, R. J., Couch, R. W. and Repetto, P. C., **Preliminary tectonic, seismic and geologic considerations for earthquake design for Lima, Peru,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 57-68. (For a full bibliographic citation, see Abstract No. 1.2-22.)

Studies of the interaction of the Nazca and South American plates indicate that two types of earthquakes could be considered for the selection of design earthquakes: (1) events at or beneath the subduction zone at hypocentral depths increasing from the continental margin towards the Andes, and (2) events within the continental crust at random locations. Preliminary field studies indicate that, in the Lima area, faults show no evidence of displacement in the Pleistocene gravel deposits and therefore need not be considered seismogenic. Large earthquakes originating at or beneath the subduction zone could possibly occur: near the surface at epicentral distances of 50 km or greater from Lima, or beneath Lima at hypocentral depths of 50 km or greater. A recurrence analysis for this type of event shows a magnitude M_b = 7.8 for an average period of 500 years; the corresponding maximum ground surface acceleration is about 0.4 g. Shallow earthquakes originating within the continental crust could be considered with a magnitude M_b = 6.0 at hypocentral depths of 10 to 20 km; maximum ground surface acceleration for a 10 km hypocentral depth is about 0.25 g.

● 2.4-76 Tapia Galvan, M., **Seismic risk and seismicity of the north-east region of Venezuela** (Riesgo sismico y

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

sismicidad en la region nor-orientalde Venezuela, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering*, Vol. II, 93–108. (For a full bibliographic citation, see Abstract No. 1.2–22.)

This paper provides the design engineer a simple and short technique to evaluate the seismicity and seismic risk in northeast Venezuela. The seismic risk of the area has been studied, taking into account 147 records of earthquakes with magnitudes between 2.8 and 6.7, active faults in the region, and dynamic subsoil parameters. The maximum probable accelerations, velocities, and displacements on the surface of soils thicker than 10 m are presented. Included in the text are a tectonic map of the area and maps of accelerations and velocities for return periods of 20, 45, and 106 years. Also included are graphs for determining the regional seismicity, the risk vs. return periods, and the acceleration, velocity, and displacement response spectra, taking into account the fundamental period and the thickness of the soils.

2.4-77 Erkhov, V. A., **The relationship between seismicity and deep structure of the northern Tien Shan region** (Svyaz'seismichnosti s glubinnym stroeniem severnogo Tyan'-Shanya, in Russian), *Geologo-Geofizicheskie Osobennosti i Seismichnost' Territorii Kirgizii,* Ilim, Frunze, U.S.S.R., 1978, 47–50.

Submeridional faults acting as dampers in the transmission of elastic seismic vibrations were identified by analyzing the relationship between seismicity and the deep structure of the northern Tien Shan region. A geophysical explanation is offered for the lack of any direct seismological relationship between the eastern and western parts of the northern Tien Shan range. This enhances the reliability of estimates of seismic risk made for the Frunze and Alma-Ata regions.

● 2.4-78 **Felt and damaging earthquakes. No. 1 - 1976,** International Seismological Centre, Newbury, England, 1979, 61.

This publication continues in part UNESCO's *Annual Summary of Information on Natural Disasters* and comprises all the information on felt and damaging earthquakes for 1976 that has previously been published in the *Bulletin of the International Seismological Centre.* The data are presented in tabular form. A detailed index of seismic and geographical regions is included.

● 2.4-79 Toppozada, T. R. et al., **Compilation of pre-1900 California earthquake history. Annual technical report, fiscal year 1978-79,** *Open-File Report 79-6 SAC,* California Div. of Mines and Geology, Sacramento, 1979, 316.

The 125 largest pre-1900 California earthquakes, that are listed in existing catalogs, were studied and estimates of their strength and location were made. Some 7500 newspapers and other documents were examined and about one-third provided earthquake reports. Before 1846, when the first newspaper was printed in California, the sources of data were limited to letters, diaries, histories, and records of the Franciscan missions that were established from 1769 to 1823 between San Diego and San Francisco. A complete bibliography of data sources is provided, listing the documents examined for each earthquake, and whether or not they contained reported earthquake effects.

The earthquake reports were interpreted in terms of the Modified Mercalli Scale, and isoseismal sketches were made to show the intensity and extent of each earthquake's effects. The epicenter was located in the most intensely shaken area, and the magnitude was estimated from the maximum intensity and from the size of the areas shaken at various levels of intensity.

Six epicenter maps were prepared, one each for the periods pre-1850, 1850-59, 1860-69, 1870-79, 1880-89, and 1890-99. Also, six maps showing the distribution of the reporting localities during the same six periods were prepared. These six pairs of maps clearly demonstrate that earthquakes are identified only where reporting localities existed. Before 1850, earthquakes were identified only on the coast between San Diego and San Francisco. During the 1850s and 1860s, earthquakes were identified mainly in the San Francisco Bay area and in the gold country of the northern Sierra Nevada, with no earthquakes smaller than magnitude 6 identified south of latitude 36° because of the scarcity of population there. During the 1870s, the seismicity was dominated by an M 8 earthquake in Owens Valley and an M 7 earthquake offshore near the California-Oregon border. The scarcity of population and earthquake reports in southern California continued throughout the 1870s. During the 1880s and 1890s, the reporting localities increased in southern California, and consequently smaller earthquakes were identified there.

In the 1890s, four earthquakes of M 5.9 or greater occurred within 40 km of the portion of the San Andreas fault that ruptured in 1906. During the six decades before and the seven decades after 1906, the 1890s decade was the most seismically active in this region, and this activity may have been premonitory to the great 1906 earthquake.

A comparison of the pre-1900 epicenter map with the twentieth century epicenter map of Real, Toppozada, and Parke shows similarities and important differences. Areas near San Diego, Santa Barbara, and the counties of Inyo, Stanislaus, Solano, Lassen, and Del Norte had stronger earthquakes during the last century. Also, the San Andreas fault system was significantly more active during the last century.

● *See **Preface**, page v, for availability of publications marked with dot.*

The report contains a bibliography including newspaper accounts. An abridged version of this report is available as Open-File Report 79-6 SAC (Abridged).

● 2.4-80 Iaccarino, E. and Molin, D., **Collection of macroseismic information relating to earthquakes in northeastern Italy from year 0 A.D. to April 1976** (Raccolta di notizie macrosismiche dell'Italia Nordorientale dall'anno 0 all'aprile 1976, in Italian), *RT/DISP(78)7,* Comitato Nazionale Energia Nucleare, Rome, 1978, 63.

2.4-81 Kanamori, H. and Abe, K., **Reevaluation of the turn-of-the-century seismicity peak,** *Journal of Geophysical Research,* **84,** *B11,* Paper 9B0849, Oct. 10, 1979, 6131–6139.

According to currently available earthquake catalogs, seismicity (for example, the number of events with $M_S \geq 8$) from 1897 to 1906 was significantly higher than in recent years. However, the magnitudes of the earthquakes which occurred from 1897 to 1906 were determined by Gutenberg, who used the records obtained by the undamped Milne seismograph with the assumption that the effective magnification is 5. Because of saturation of the Milne seismogram for very large events used by Gutenberg for calibration, the gain could have been underestimated and therefore the magnitude overestimated. Because of the lack of damping, the magnification of this instrument needs to be calibrated carefully. In order to calibrate the instrument response, a Milne seismograph has been constructed at Pasadena and operated side by side with damped seismographs. Eleven events have been recorded since February 1977. On the basis of (1) a comparison of the amplitudes measured on the Milne seismograms with those of the standard seismograms, (2) numerical experiments simulating the response of the Milne seismographs to surface waves, and (3) examination of Gutenberg's original materials used for the calibration, it is concluded that the average effective gain is as large as 20 for very large earthquakes, resulting in a systematic reduction of the magnitude of up to 0.6. This reduction is large enough to suggest that the turn-of-the-century seismicity peak is of marginal significance.

● 2.4-82 Watanabe, S. and Okada, Y., **Microearthquake activity in the southernmost part of Yamanashi Prefecture, central Japan (1)** (in Japanese), *Bulletin of the Earthquake Research Institute,* **54,** *Part 2,* 1979, 317–327.

The Fujigawa Crustal Movement Observatory is located near the Itoigawa-Shizuoka tectonic line and Mt. Fuji, Mt. Akashi, and Suruga Bay, Japan. Despite its geographical significance, microearthquake observation had been carried out at only one station, which limited knowledge of the seismicity of the region to the S-P distribution. To remedy this situation, tripartite observation was begun in June 1978. Prior to the start of observation, IC-type premain-power amplifiers and crystal clocks which can be corrected with time signals from a radio receiver were constructed.

As a first step, with the assumption of a semi-infinite medium, focal locations were determined geometrically from the P times at three stations and the S-P times at one station. The following information has been determined thus far. (1) A seismic zone which has a NE-SW trend is clearly seen. Although this trend does not coincide with the geological trend, it may coincide with a general trend of seismicity in a wider area around the tripartite. (2) Along the Itoigawa-Shizuoka tectonic line, rather high seismicity can be seen, although it is scattered. (3) The seismicity near Mt. Fuji and Mt. Akashi seems to be low, as does the seismicity of the mouth of the Fuji River, which is the innermost part of Suruga Bay.

Regarding the seismicity along the southern part of the Itoigawa-Shizuoka tectonic line, one interesting fact was found by use of Japan Meteorological Agency (JMA) data. There was very little seismic activity in this area from 1969 to 1973. This emphasizes the fact that the crustal movement in the central part of Japan has changed its general tendency.

2.4-83 Berry, M. J. and Hasegawa, H. S., **Seismic risk and toxic waste disposal: a discussion,** *Geoscience Canada,* **6,** *4,* Dec. 1979, 195–198.

Earthquakes, whether natural or induced, pose a significant risk to the disposal of toxic wastes by burial or fluid injection in the crust. Methodology exists for assessing the ambient seismic risk at moderately low levels of probability, but for greater degrees of conservatism the assessment is essentially deterministic. Such estimates are considered appropriate for periods comparable to that of the available seismic history but an improved understanding of the nature of currently active seismic zones is required for the estimates to be applied with confidence to periods of time measured in thousands of years. The potential hazards associated with this natural seismic risk can be mitigated by appropriate engineering design and practice. Induced seismicity associated with mining excavations, thermally induced stresses, or fluid injection can be controlled by appropriate engineering design and operational procedure.

● 2.4-84 Borg, S. F., **An isoseismal-energy correlation for use in earthquake structural design,** *Technical Report ME/CE-792,* Dept. of Mechanical Engineering/Civil Engineering, Stevens Inst. of Technology, Hoboken, New Jersey, Dec. 1979, 28.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

A fundamental invariant (or correlation) for the earthquake phenomenon is studied in this report. The analysis presents a rational analytical representation for an isoseismal map. Five separate earthquakes in different parts of the world that occurred over the past 100 years are used to check and correlate the data. The invariant is of basic importance in energy analyses of the earthquake event and may be of use in studies of the earthquake mechanisms as well as in applications to practical structural design. In addition, it introduces new parameters that may be of importance in earthquake studies.

● **2.4-85** Arabasz, W. J., Smith, R. B. and Richins, W. D., eds., **Earthquake studies in Utah: 1850 to 1978,** Seismographic Stations, Dept. of Geology and Geophysics, Univ. of Utah, Salt Lake City, July 1979, 552.

● **2.4-86** Mooney, H. M., **Earthquake history of Minnesota,** *Minnesota Geological Survey Report of Investigations 23*, Univ. of Minnesota, St. Paul, 1979, 20.

● **2.4-87** Agbabian Assocs., **A review of earthquake vibratory ground motion intensity attenuation relationships-topical report,** *SAN-1011-119*, Div. of Reactor Research and Technology, U.S. Dept. of Energy, Washington, D.C., Sept. 1978, 97.

The objective of this report is to provide a review of earthquake vibratory ground motion intensity-distance-attenuation relationships which depicts the evolution and limitations of currently used procedures. Two general procedures are considered; one procedure relates peak horizontal ground acceleration, earthquake magnitude, and distance, and the other relates epicentral Modified Mercalli Intensity (MMI), distance, and attenuated MMI. A conversion relationship between MMI and peak horizontal ground acceleration is used with the latter.

The study concludes that based on present knowledge peak horizontal ground acceleration-magnitude-distance attenuation relationships that give lower values than those indicated by Schnabel and Seed are not recommended for regions of thrust faulting in western United States where focal depths of 10 to 15 km, or less, are anticipated and accompanied with surface manifestations of faulting. It also concludes that the Schnabel and Seed relationships are equally applicable to rock or stiff soil sites at source distances greater than 30 km. Professional judgment is required to estimate peak horizontal ground accelerations for sites in other regions of the United States, and for different fault conditions and focal depths.

The study also concludes that in regions where MMI data must be used to estimate rates of attenuation of ground motion intensity there is a strong need to adjust past assigned MMI values which reflect the level of damage experienced to better reflect the rate of attenuation of intensity of ground motion (i.e., peak horizontal ground acceleration). The study finds that correlations between MMI and peak horizontal ground acceleration by Trifunac and Brady and by Murphy and O'Brien have associated accelerations with the area between isoseismal lines but that Gutenberg and Richter used a reference base associated with the isoseismal lines. When this adjustment is made to the Murphy and O'Brien data, close agreement is obtained with the Gutenberg and Richter relationship. Adjustment of the 1971 San Fernando data used by Trifunac and Brady to better reflect the rate of attenuation of acceleration, and to represent accelerations at the boundaries of the individual intensity areas also gives values that are in close agreement with the Gutenberg and Richter relationship. Therefore, it is concluded that the Gutenberg and Richter relationship gives the best average values based on California earthquake data. However, the reference base with this relationship should be the isoseismal lines rather than the midpoints of areas between isoseismal lines.

2.4-88 Savinov, O. A., **Seismogenic faults and seismic risk evaluation at large dam building sites** (Seismogennye razryvy i otsenka seismicheskoi opasnosti na uchastkakh stroitel'stva bol'shikh plotin, in Russian), *Seismotektonika yuzhnykh raionov SSSR*, Nauka, Moscow, 1978, 121-126.

Types of seismic hazard are characterized; these risk categories must be taken into account in approving plans for large dams sited in seismically active areas. Forecasts of features of seismic vibrations and of irreversible displacements of blocks forming the base for a future structure or water reservoir basins must be based in all cases on data referrable to faulted zones of differentiated tectonic movements, and to the determination of degrees of seismogenicity of large faults near the hydroelectric power installation site. Prediction of the time of occurrence of a strong-motion earthquake can yield benefits only when it is done in relation to some major seismogenic fault.

● **2.4-89** Bollinger, G. A. and Mathena, E., comps., **Seismicity of the southeastern United States, July 1, 1978-December 31, 1978,** *Bulletin 3*, Dept. of Geological Sciences, Virginia Polytechnic Inst. and State Univ., Blacksburg, May 1979, 69.

This report contains a tabular listing by state of the 81 seismic stations operating in the southeastern United States from July to Dec. 1978. The information included in the table is as follows: (1) a three- or four-letter station code; (2) the station latitude in decimal degrees, north; (3) the station longitude in decimal degrees, west; (4) the station elevation in meters; (5) the geographic name of the station; and (6) the network operator responsible for the station. Included are a geographic map of the southeastern U.S. Seismic Network figures showing the networks in South

● *See **Preface**, page v, for availability of publications marked with dot.*

Carolina; Giles County, Virginia; central Virginia, including North Anna and Bath counties; and Wallace Dam, Georgia. Each of these networks has station spacings too close to be shown clearly on the map, but an appendix gives general station information and magnification curves. This report also contains a table of the epicentral parameters for earthquakes that occurred in the southeastern U.S. during the report period along with arrival-time data and magnitude estimates. Most items in the listing are self-explanatory, and all times are Coordinated Universal Time. Also included in the report are an epicentral map for the report period and a cumulative epicentral map for the period from July 1, 1977, through Dec. 31, 1979. There were 9 earthquakes detected and located during the report period. Microearthquake activity was reported for locales in Georgia, South Carolina, and Virginia.

2.5 Studies of Specific Earthquakes

● **2.5-1** Langer, C. J. and Bollinger, G. A., **Secondary faulting near the terminus of a seismogenic strike-slip fault: aftershocks of the 1976 Guatemala earthquake,** *Bulletin of the Seismological Society of America,* **69**, *2*, Apr. 1979, 427–444.

Aftershocks of the Feb. 4, 1976, Guatemalan earthquake (M_S = 7.5) were monitored by a network of portable seismographs from Feb. 9 to Feb. 27. Although seismic data were obtained all along the 230-km surface rupture of the causal Motagua fault, the field program was designed to concentrate on the aftershock activity at the western terminus of the fault. Data from that locale revealed several linear or near-linear trends of aftershock epicenters that splay to the southwest away from the western end of the main fault. These trends correlate spatially with mapped surface lineaments and, to some degree, with ground breakage patterns near Guatemala City. The observed splay pattern of aftershocks and the normal-faulting mode of the splay earthquakes determined from composite focal mechanism solutions may be explained by a theoretical pattern of stress trajectories at the terminus of a strike-slip fault. Composite focal mechanism solutions for aftershocks located on or near the surface break of the Motagua fault, to the north and east of the linear trend splay area, agree with the mapped surface movements, i.e., left-lateral strike-slip.

● **2.5-2** Hanks, T. C., **The Lompoc, California, earthquake (November 4, 1927; *M* = 7.3) and its aftershocks,** *Bulletin of the Seismological Society of America,* **69**, *2*, Apr. 1979, 451–462.

Local seismological observations of the 1927 earthquake suggest an epicenter near 34.6°N, 120.9° W. These observations include *S-P* times for the immediate aftershocks recorded at four stations in southern California; *S-P* times reported for the main shock at Berkeley and Lick Observatory by P. Byerly; and a time-decaying (1934 to 1969) zone of seismicity centered offshore of Point Arguello, herein identified as the aftershock zone of the 1927 earthquake. This location is approximately 40 km southwest of the teleseismic location for the 1927 earthquake recently offered by W. Gawthrop, although a location intermediate to the one proposed here and the one by Gawthrop would satisfy uncertainties associated with both locations. Even so, the location farther offshore is suggested by the near absence of strong shaking in the adjacent coastal region, which seemingly precludes a near-coastal location for an earthquake of this magnitude. Furthermore, unpublished teleseismic first-motion data of G. Stewart and analysis of the distortion of a geodetic quadrilateral by J. Savage and W. Prescott argue against a faulting mechanism for the 1927 earthquake that involves predominantly right-lateral slip on a near-coastal and northwesterly striking fault of the San Andreas type.

● **2.5-3** Pitt, A. M., Weaver, C. S. and Spence, W., **The Yellowstone Park earthquake of June 30, 1975,** *Bulletin of the Seismological Society of America,* **69**, *1*, Feb. 1979, 187–205.

The June 30, 1975, Yellowstone Park earthquake (M_L 6.1, M_S 5.9) occurred on the north-central boundary of the Yellowstone caldera. Intensity studies show the felt area north of the epicenter to be substantially larger than the felt area south of the epicenter. This asymmetry may be due to attenuation of seismic waves propagating through the caldera. Aftershocks define a 10-km northwest-trending zone of seismicity centered on the main shock. A second zone of seismicity (active since Mar. 1974), located 5 km west of and subparallel to the zone containing the main shock, increased in length during the aftershock sequence. No faults are mapped in the region of either zone, but north-to-northwest-trending normal faults are found north of the caldera boundary. Focal mechanisms indicate both normal and oblique-slip faulting, but normal faulting predominates. The *T* axes are oriented northeast (perpendicular to the two seismic zones) suggesting block faulting. Elevation changes of 12 cm (determined by first-order level lines) between Madison Junction (up) and Mammoth Hot Sprints (down) between 1960 and Aug. 1975 are interpreted as a long-term trend with a local perturbation in the Norris Junction area which may have been caused by the June 30 earthquake.

● **2.5-4** Bennett, J. H. et al., **Stephens Pass earthquakes: Mount Shasta-August 1978, Siskiyou County, CA,** *California Geology,* 32, *2*, Feb. 1979, 27–34.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● 2.5-5 Bryant, W. A., **Earthquakes near Honey Lake-Lassen County, California,** *California Geology,* 32, 5, May 1979, 106-109.

A moderate earthquake (M 5.2, Berkeley) occurred at 7:57 a.m. on Feb. 22, 1979, in Lassen County, California. The epicenter was located in the southeast portion of Honey Lake Valley about 80 km north of Truckee.

● 2.5-6 Butler, R., Stewart, G. S. and Kanamori, H., **The July 27, 1976 Tangshan, China earthquake—a complex sequence of intraplate events,** *Bulletin of the Seismological Society of America,* 69, *1,* Feb. 1979, 207-220.

The Tangshan earthquake (M_S = 7.7), of July 27, 1976, and its principal aftershock (M_S = 7.2), which occurred 15 hr following the main event, resulted in the loss of life of over 650,000 persons in northeast China. This is the second greatest earthquake disaster in recorded history, following the 1556 Shensi Province, China, earthquake in which at least 830,000 persons lost their lives. Detailed analyses of the teleseismic surface waves and body waves are made for the Tangshan event. The major conclusions are (1) The Tangshan earthquake sequence is a complex one, including strike-slip, thrust, and normal-fault events. (2) The main shock, as determined from surface waves, occurred on a near vertical right-lateral strike-slip fault, striking N40°E. (3) A seismic moment of 1.8 X 10^{27} dyne-cm is obtained. From the extent of the aftershock zone and relative location of the main shock epicenter, symmetric (1:1) bilateral faulting with a total length of 140 km may be inferred. If a fault width of 15 km is assumed, the average offset is estimated to be 2.7 m with an average stress drop of about 30 bars. (4) The main shock was initiated by an event with a relatively slow onset and a seismic moment of 4 X 10^{26} dyne-cm. The preferred fault-plane solution, determined from surface-wave analyses, indicates a strike 220°, dip 80°, and rake -175°. (5) Two thrust events follow the strike-slip event by 11 and 19 sec, respectively. They are located south to southwest of the initial event and have a total moment of 8 X 10^{25} dyne-cm. This sequence is followed by several more events. (6) The principal aftershock was a normal-fault double event with the fault planes unconstrained by the *P*-wave first motions. Surface waves provide additional constraints to the mechanism to yield an oblique slip solution with strike N120°E, dip 45°SW, and rake -30°. A total moment of 8 X 10^{26} dyne-cm is obtained. (7) The triggering of lesser thrust and normal faults by a large strike-slip event in the Tangshan sequence has important consequences in the assessment of earthquake hazard in other complex strike-slip systems like the San Andreas.

● 2.5-7 Yoshikawa, S. et al., **Ground motion near causative fault of Kita-Tango earthquake of 1927,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 53-71.

This paper describes the estimated characteristics of ground motion on the base rock near the fault in the Kita-Tango earthquake, which occurred in southwestern Japan on Mar. 7, 1927 (M = 7.5). The ground motions at the top subsurface were calculated by assuming the constant particle velocity amplitude of the source spectra. The response spectral values at 11 sites with different distances from the fault are found to have good correlation with the damage ratio of a wooden house structure.

● 2.5-8 Faccioli, E. and Agalbato, D., **Attenuation of strong-motion parameters in the 1976 Friuli, Italy, earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 233-242.

Attenuation trends exhibited by the Friuli data are in good agreement with western United States trends as regards peak ground accelerations, but the trends lead to predictions of substantially lower peak velocity and displacement values, as well as a different behavior for spectral ordinates. Some of these differences may be as a result of the more sophisticated procedures for accelerogram correction introduced in this study. Attenuation laws for peak acceleration and velocity based on previous European data give unacceptably high estimates for the Friuli events. The analysis of near-field data revealed that the Friuli earthquakes were characterized by relatively low peak ground motions and that local site conditions of a certain type can give rise to abnormally high accelerations under suitable combinations of source magnitude and distance.

● 2.5-9 Hartzell, S. and Brune, J. N., **The Horse Canyon earthquake of August 2, 1975-two-stage stress-release process in a strike-slip earthquake,** *Bulletin of the Seismological Society of America,* 69, *4,* Aug. 1979, 1161-1173.

A moderate strike-slip earthquake (M_L = 4.8) occurred on the San Jacinto fault system about 60 km northwest of the Salton Sea on Aug. 2, 1975. Analyses of main shock and aftershock data suggest that stress release during this earthquake took place in two stages. During one stage, faulting occurred over a relatively small source area (source radius of ~0.5 km), with a rapid dislocation rate (rise time ~0.1 sec), possibly associated with an asperity on the fault. During the second stage of faulting, the rupture front grew, but at a much slower rate (rise time ~10 sec), to a final source radius of ~1.0 km. The above model explains the larger moment estimate based on 20-sec surface waves compared to shorter period body-wave estimates, and also the apparent increase in source dimension with time. The model allows for large stress drops over small source

● *See **Preface,** page v, for availability of publications marked with dot.*

dimensions, but when averaged over the final extent of the rupture plane, stress drops are much lower. The rupture of the asperity is characterized by a moment of 6.5 X 10^{22} dyne-cm and a stress drop of about 225 bars. The total moment is about 3.0 X 10^{23} dyne-cm with an averaged stress drop over the fault plane of approximately 90 bars and a dislocation of 25 cm. Observations similar to the ones reported here have been noted for other earthquakes with a wide range of magnitudes, including a few large earthquakes in Japan, the 1971 San Fernando earthquake and some of its aftershocks, the 1975 Oroville earthquake, and some swarm events in the Imperial Valley. These observations suggest that a two-stage rupture mechanism may be a fairly common occurrence in shallow faulting and may reflect possible large variations in stress over a length scale of kilometers within the crust.

● **2.5-10** Bakun, W. H. and McEvilly, T. V., **Earthquakes near Parkfield, California: comparing the 1934 and 1966 sequences,** *Science,* **205,** *4413,* Sept. 28, 1979, 1375-1377.

Moderate-sized earthquakes (Richter magnitude M_L 5 1/2) have occurred four times in this century (1901, 1922, 1934, and 1966) on the San Andreas fault near Parkfield in central California. In many respects, the June 1966 sequence was remarkably similar to the June 1934 sequence, suggesting a recurring recognizable pattern of stress and fault zone behavior.

2.5-11 Rogers, G. C. and Ellis, R. M., **The eastern British Columbia earthquake of February 4, 1918,** *Canadian Journal of Earth Sciences,* **16,** *7,* July 1979, 1484-1493.

As a result of damage, felt reports, and the number of instrumental observations, the Feb. 4, 1918, earthquake in east-central British Columbia has in the past been assigned a location near Revelstoke and a magnitude of about 5. It is the largest historical earthquake that has occurred in the eastern part of the Canadian Cordillera. Reexamination of this earthquake using seismograms from Spokane, Saskatoon, and Ottawa, along with newspaper reports, indicates that the event was located approximately 150 km north of Revelstoke and had a magnitude m_{bLg} of 5.6 to 6.1. Examination of this and more recent events indicates that the *Lg* phase, which in general is not well observed at Cordilleran stations, may efficiently propagate in this region.

● **2.5-12** Slawson, W. F. and Savage, J. C., **Geodetic deformation associated with the 1946 Vancouver Island, Canada, earthquake,** *Bulletin of the Seismological Society of America,* **69,** *5,* Oct. 1979, 1487-1496.

A recent reexamination by Rogers and Hasegawa of the available seismic data from the June 23, 1946, Vancouver Island earthquake (M_S = 7.2) indicates that the earthquake was of relatively shallow (30 km or less) focal depth and the epicenter was located in central Vancouver Island rather than beneath the Strait of Georgia some 30 km or more to the east as previously thought. The authors tested the Rogers-Hasegawa solution by resurveying a triangulation network in the epicentral area which had first been surveyed in 1935. The distortion of the network was found to be greater than could be accounted for by either secular strain accumulation as indicated by measurements of a nearby network or survey error but is consistent with oblique slip on a section of the Beaufort Range fault, a prominent fault that crosses the triangulation network. The best model for slip on the Beaufort Range fault involves 1.00 ± 0.25 m right-lateral and 2.50 ± 0.65 m normal slip on a shallow (0 to 5 km) segment dipping 70° NE. However, pure right-lateral slip of about 1 m over a depth interval of 0 to 20 km on a vertical fault is not excluded at the 90 percent confidence limit. Thus, the geodetic data support the conclusions of Rogers and Hasegawa that the 1946 earthquake was caused by right-lateral, normal slip on the Beaufort Range fault in the vicinity of Forbidden Plateau, central Vancouver Island.

● **2.5-13** Heaton, T. H. and Helmberger, D. V., **Generalized ray models of the San Fernando earthquake,** *Bulletin of the Seismological Society of America,* **69,** 5, Oct. 1979, 1311-1341.

The exact Cagniard-de Hoop solutions for a point dislocation in a halfspace are used to construct models of the strong ground motion observed during the Feb. 9, 1971, San Fernando earthquake (M_L = 6.4). By summing point dislocations distributed over the fault plane, three-dimensional models of a finite fault located in a halfspace are constructed to study the ground motions observed at JPL (Pasadena), Palmdale, Lake Hughes, and Pacoima Dam. Since the duration of faulting is comparable to the travel times for various wave types, very complex interference of these arrivals makes a detailed interpretation of these wave forms difficult. By investigating the motion caused by small sections of the fault, it is possible to understand how various wave types interfere to produce the motion caused by the total fault. Rayleigh waves as well as S to P head waves are shown to be important effects of the free surface. Near-field source effects are also quite dramatic. Strong directivity is required to explain the difference in amplitudes seen between stations to the north and stations to the south. Faulting appears to have begun north of Pacoima at a depth of 13 km. The rupture velocity, which is near 2.8 km/sec in the hypocentral region, appears to slow to 1.8 km/sec at a depth of 5 km. Displacements on the deeper sections of the fault are about 2.5 m. Fault offsets become very small at depths near 4 km and then grow again to 5 m near the surface rupture. The

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

large velocity pulse seen at Pacoima is a far-field shear wave which is enhanced by directivity. Peak accelerations at Pacoima are probably associated with the large shallow faulting. The total moment is 1.4 x 10^{26} ergs.

● 2.5-14 Kanamori, H. and Stewart, G. S., **Seismological aspects of the Guatemala earthquake of February 4, 1976,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 38, 13.

Detailed analyses of teleseismic surface waves and body waves from the Guatemala earthquake of Feb. 4, 1976, show that: (1) Left-lateral displacement along a vertical fault with a strike varying from N66°E to N98°E is consistent with the teleseismic data. (2) The seismic moment was 2.6 x 10^{27} dyne-cm. The directivity of the surface-wave radiation indicates an asymmetric (1:2.3) bilateral faulting with a total length of 250 km. In modeling the displacement, a rupture velocity of 3 km/sec was used and the fault curvature included. (3) If a fault width of 15 km is assumed, the average offset is estimated to be about 2 m. This value is about twice as large as the average surface offset. (4) Although the observed directivity suggests a uniform overall displacement along the fault, the body-wave analysis suggests that the earthquake consists of as many as ten independent events, each having a seismic moment of 1.3 to 5.3 x 10^{26} dyne-cm and a fault length of about 10 km. The spatial separation of these events varies from 14 to 50 km. This multiple shock sequence suggests that the rupture propagation is jagged and partially incoherent with an average velocity of 2 km/sec. (5) The average stress drop estimated from surface waves is about 30 bars, but the local stress drop for the individual events may be significantly higher than this. (6) The complex multiple event is a manifestation of a heterogeneous distribution of the mechanical properties along the fault which may be caused by either asperities, differences in strength, differences in pore pressure, differences in slip characteristics (stable sliding versus stick slip) or combinations of these factors. (7) This complexity has important bearing on the state of stress along transform faults and is important in assessing the effect of large earthquakes along other transform faults like the San Andreas.

● 2.5-15 Stickney, M. C., **The Fort Ross earthquake sequence, March and April, 1978,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1841-1849.

On Mar. 31, 1978, an earthquake of coda magnitude 3.3 (M_L = 3.7 BRK) occurred 5 km off the coast of northern California near Fort Ross. A single foreshock preceded the earthquake and approximately 60 aftershocks followed. Locations based on *P*- and *S*- wave arrival times indicate that the earthquakes occurred offshore, west of the San Andreas fault in the vicinity of a fault that is visible on acoustic reflection profiles. All earthquakes had hypocentral depths less than 8 km. A fault-plane solution from *P*-wave first motions suggests that the focal mechanism of the main shock consisted of nearly equal components of dextral and vertical movement on a plane striking northwest. Other events in this sequence had first-motion patterns strikingly different than the main shock, indicating that more than one type of faulting occurred during the sequence. Seismic moments computed for three aftershocks ranged from 3.8 x 10^{19} to 1.1 x 10^{19} dyne-cm.

● 2.5-16 Unger, J. D. and Ward, P. L., **A large, deep Hawaiian earthquake—the Honomu, Hawaii event of April 26, 1973,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1771-1781.

The largest subcrustal earthquake ever recorded from the Hawaiian island chain (magnitude 6.2) occurred at a depth of 48 km on Apr. 26, 1973. The proximity of the Hawaiian Volcano Observatory's extensive seismograph network and the authors' knowledge of the crustal and upper mantle structure beneath the island made it possible to calculate accurate hypocenters for both the main shock and 57 aftershocks. The earthquake may have triggered swarms of small, shallow earthquakes at two different locations on the island: one 25 km and the other 50 km from the epicenter of the earthquake. The polarity of the *P*-wave arrivals for the main shock and most of the aftershocks, as recorded by the local network and worldwide stations, define nodal planes oriented N26°E dipping 77°W and N70°W dipping 61°S. Comparison of the inferred directions of the greatest and least principal stresses derived from these data with the stress direction within the Pacific plate assumed for various hypotheses of the formation of the Hawaiian island chain show closest agreement with the concept that the orientation of the archipelago is aligned parallel to the direction of the maximum shear stress and is not perpendicular to the orientation of the least principal stress.

● 2.5-17 Cagnetti, V. and Pasquale, V., **The earthquake sequence in Friuli, Italy, 1976,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1797-1818.

The seismic activity of the May 6, 1976, Friuli earthquake has been investigated. It provides clear evidence of internal clustering of shocks, with the largest aftershocks being followed by their own series of aftershocks. Late large aftershocks with their own aftershock series occurred four months after the main shock, when aftershocks had subsided. Thus, in the entire series of aftershocks, six phases of strain release are found, and part of the aftershock region is not included in the aftershock volume of the main shock. All this indicates that a few aftershocks are at least partially independent from the main shock. The value of *b* is estimated for the entire sequence and for the separate phases; during the activity, *b* shows an increase after the main shock, a decline immediately before the largest

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

aftershock, and a second increase immediately afterward. This can be explained in terms of stress changes, and is consistent with laboratory studies of rock deformation. The compressive stress is perpendicular to the Eastern Alps, and may be considered as the principal cause of the earthquake sequence. The solution of the main shock of the sequence is a reversed fault movement, unlike most of the mechanisms in the focus of the earlier Friuli earthquakes which are of the transcurrent type.

● 2.5-18 Berberian, M. et al., **Mechanism of the main shock and the aftershock study of the Tabas-e-Golshan (Iran) earthquake of September 16, 1978: a preliminary report**, *Bulletin of the Seismological Society of America*, **69**, *6*, Dec. 1979, 1851-1859.

Aftershocks of the Tabas-e-Golshan earthquake (M_S = 7.7) of Sept. 16, 1978, were recorded with a local network of portable seismometers. The main shock produced a discontinuous series of surface ruptures extending 85 km NNW and dipping ENE beneath the Shotori Range. The largest aftershocks located thus far are not concentrated in the hypocentral region of the main shock nor near the ends of the rupture zone but appear to be concentrated down-dip from gaps in the surface ruptures. This suggests that these features may extend to depth and act as barrier zones in the rupture process. The 65-km-long zone of aftershock activity dips 40°ENE from the surface break, which agrees with the focal mechanism for the main shock in indicating thrusting on a NNW-striking, ENE-dipping fault. The aftershocks range in depth from 2 to 24 km, with greatest concentration in the depth range 5 to 10 km.

● 2.5-19 Berberian, M., **Earthquake faulting and bedding thrust associated with the Tabas-e-Golshan (Iran) earthquake of September 16, 1978**, *Bulletin of the Seismological Society of America*, **69**, *6*, Dec. 1979, 1861-1887.

The Tabas-e-Golshan earthquake of magnitude M_S = 7.7 occurred in a region of east central Iran known to have been quiescent for at least 11 centuries. The shock was associated with 85 km of discontinuous thrust faulting at the surface along an existing but unrecognized late Quaternary fault (the Tabas fault). Nearly all the surface breaks followed the obvious scarps created by the previous faulting. An extensive zone of "bedding thrusts" (bedding-plane slip) was also developed in the Neogene clay deposits of the overthrust block, east of the main fault zone. Minimum vertical uplift (throw) and slip were measured to be about 150 and 300 cm, respectively. The deformation caused by this earthquake indicates crustal thickening of the region, i.e., uplifting along the earthquake fault. The Tabas fault is one of the principal structures by which the western flank of the Shotori Mountains is raised about 2 km above the alluvial deposits of the Tabas compressional graben. It is a multi-role, deep-seated Precambrian fault that was a major feature of the Paleozoic and Mesozoic eras in the western part of the fault-controlled subsiding sedimentary basin of Shotori.

The earthquake killed more than 20,000 people and severely damaged or destroyed about 90 villages including the town of Tabas. This catastrophic event emphasizes once more the importance of mapping recent faults and the careful field study of structures associated with low-magnitude buried earthquakes. In the case of Tabas, the lack of historical seismic damage over the past 11 centuries meant that there had been no adequate assessment of the seismicity and seismic hazard on this basis. A comparison of the Plio-Pleistocene and Late Quaternary crustal deformation with that associated with this earthquake indicates that the intra-plate deformation is essentially unchanged since that time and that the regional stress field has not greatly changed since the late Alpine phase.

The present state of knowledge about regional tectonics and seismicity suggests that the country is a broad zone of compressional deformation, the present deformation being taken up mostly by the existing late Quaternary mountain-bordering reverse faults inherited from the old geological times. The seismicity is widespread along several faults and the continental crust is thickening and shortening in the NE-SW direction.

● 2.5-20 Hawkins, H. G. and McNey, J. L., **Homestead Valley earthquake swarm: San Bernardino County, California**, *California Geology*, **32**, *10*, Oct. 1979, 222-224.

A swarm of earthquakes occurred on Mar. 15, 1979, shaking a large portion of southern California. There were five events between 12:17 p.m. and 3:17 p.m. with magnitudes (M) ranging from M 4.1 to M 5.2. At least 24 events were recorded by 12 p.m. Mar. 16, 1979. This article describes the surface rupture caused by the earthquake and the effects of ground shaking.

2.5-21 Popova, E. V., **Residual soil deformations in earthquakes (part IV)** (Ostatochnye deformatsii gruntov pri zemletryaseniyakh (chast' IV), in Russian), *Voprosy inzhenernoi seismologii*, *19*, 1978, 171-190.

Dimensions of residual deformations are cited for 18 strong-motion earthquakes recorded in the U.S.S.R., Mexico, Iran, and Japan. Special attention is given to data on the 1968 Dasht-e-Bayaz earthquake in Iran. Tectonic, geological, and hydrogeological conditions are considered, along with intensity, duration, magnitude, and depth of the earthquake focus.

2.5-22 Ando, M., **The Hawaii earthquake of November 29, 1975: low dip angle faulting due to forceful injection of magma**, *Journal of Geophysical Research*, **84**, *B13*, Paper 9B0992, Dec. 10, 1979, 7616-7626.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

The mechanism of the Hawaii earthquake of November 29, 1975 (M_S = 7.1), which took place on the south flank of the Kilauea Volcano, is discussed on the basis of a comprehensive set of body wave and surface wave data, the aftershock distribution, and tsunami and crustal deformation data. The aftershock distribution defines a gently dipping plane at about 10-km depth beneath the south flank of Kilauea. This suggests that the shallowly dipping *P*-wave nodal plane fits the fault of the Hawaii earthquake better than the nodal plane that has a nearly vertical dip angle. The fault length is fixed well by the aftershock distribution, which is also consistent with the tsunami and crustal deformation data. The fault width which is obtained from tsunami and crustal deformation data is, however, significantly greater than that obtained from the aftershock distribution. This discrepancy implies that about half the main shock fault plane was not associated with aftershock activity. The source parameters are strike N70°E; dip angle 20°SSE; fault length 40 km; seismic moment 1.8 x 10^{27} dyne-cm; fault width 20-30 km; fault movement is pure normal dip slip of 3.7-5.5 m, and stress drop is 43-93 bars. Results of geodetic surveys throughout the twentieth century and a history of volcanic activity on Kilauea imply that a north-south compression due to magma injected into rift zones may have steadily increased on the south flank of Kilauea since the 1868 earthquake, an event comparable to the 1975 shock. This compressional stress was possibly released by the 1975 Hawaii earthquake. The long-term eruptive activity of Kilauea may be affected by large earthquakes like the 1868 and 1975 events and may also have a similar 100-yr recurrence interval.

2.5-23 Jackson, J. et al., **Seismotectonic aspects of the Markansu Valley, Tadjikstan, earthquake of August 11, 1974,** *Journal of Geophysical Research,* 84, *B11,* Paper 9B0789, Oct. 10, 1979, 6157-6167.

The Markansu Valley earthquake of Aug. 11, 1974 (m_b = 6.4) occurred in a structurally complex area of the northern Pamir. It was followed by more than 80 teleseismically recorded aftershocks, 13 with M_b greater than or approximately equal to 5.0. Fault plane solutions for the three largest aftershocks differ from one another and from the main shock and indicate both thrust and strike slip faulting. Geological mapping and aftershock locations suggest that the strike slip faulting occurred on both the north and northwest trends. The region is one in which large northwest trending strike slip faults converge. To the north and south, these faults are very clear topographic features. As the faults approach the northeastern Pamir, they become less distinct on the Landsat imagery, although they remain recognizable geologic features on the ground. The strike slip faults become less distinct toward their ends perhaps because the north-south motion is taken up progressively by east-west striking thrusts. It is not possible to fit orthogonal nodal planes to all the observed first motions of the P waves from the main shock. The earthquake is located at the intersection of two inferred fault systems and appears to be a multiple rupture. The discrepant P wave first motions are all nodal in character. If faulting occurred on more than one fault plane during the main shock, then the apparent first motions in the nodal directions of the first rupture may be anomalous and actually belong to a rupture later than the first one. The authors are aware of one other similar occurrence: the 1967 Mudurnu, Turkey, earthquake, for which the few anomalous P wave first motions were also nodal and for which the fault plane solutions of the main shock and the largest aftershock are very different. The concentration of large earthquakes near the intersection of two systems is also observed in Iran. The seismic moment of the main shock of the Markansu Valley sequence is about 5 x 10^{26} dyne cm.

2.6 Seismic Water Waves

2.6-1 Nishenko, S. and McCann, W., **Large thrust earthquakes and tsunamis: implications for the development of fore arc basins,** *Journal of Geophysical Research,* **84**, *B2,* Feb. 10, 1979, 573-584.

Variations of the subduction regime around the Pacific are reflected by changes in the lengths of rupture zones and the source areas for tsunamis associated with large shallow earthquakes. Crustal deformation occurring during the earthquake and related tsunamic activity plays an important role in the development and maintenance of topographic features in the fore arc region. A regional comparison of the average length of upper slope basins and terraces with the maximum length of earthquake rupture zones shows that longer basins and terraces characteristically occur in regions with larger rupture zones. Examples from Japan, Alaska, and the Aleutians clearly show how these topographic features reflect the size and spatial distribution of seismic-tsunamic source areas. In many areas, this relationship may be explained by the coseismic reactivation of structural units within the fore arc region. The two principal areas of coseismic reactivation are the trench slope break and the frontal arc region. Thus, upper slope basins, deep sea terraces, and other bathymetric features may serve as indicators of the tectonic regime and the seismic-tsunamic risk along convergent margins. Variations of the dimensions of rupture zones also appear to be influenced by the blocklike behavior of the overthrust plate. In many instances, the dimensions of upper slope basins and terraces are equivalent to those of the crustal blocks. Regions with basin or terrace lengths greater than 100 km have histories of large ruptures involving adjacent segments. Regions with basin or terrace dimensions less than 100 km tend to rupture independently of adjacent segments.

● 2.6-2 Houston, J. R., **Tsunamis, seiches, and landslide-induced water waves,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States,*

● See ***Preface***, *page v, for availability of publications marked with dot.*

Report 15, Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Nov. 1979, 90.

State-of-the-art methods are presented to assess the hazards of tsunamis, seiches, and landslide-induced water waves in the United States. Tsunami hazard maps for the United States are shown that display tsunami elevation zones that have a 90% probability of not being exceeded in a 50-year period. Methods used to determine forces exerted on structures by tsunamis are described. Hydrodynamic aspects of seiches and landslide-induced water waves are discussed, as well as methods of assessing the hazards associated with these phenomena.

● 2.6-3 Brandsma, M., Divoky, D. and Hwang, L., **Tsunami atlas for the coasts of the United States,** *NUREG/CR-1106*, Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Nov. 1979, 42.

Coastal power plant siting and safety analysis requires consideration of wave action and extreme water levels, both high and low. The run-up of large amplitude long waves, such as tsunamis, may pose a hazard to a coastal facility through direct dynamic effects on plant structures, through destruction of protective breakwaters and beaches, and the like. Extreme low water levels are of concern in design of coolant intake structures. The importance of tsunamis in these analyses, especially along the Pacific coasts, makes specification of potential tsunami histories necessary. The present report addresses this problem. A large hypothetical earthquake is defined by application of history and tectonic theory. This canonical source serves as input to a numerical hydrodynamic model which computes the resulting wave history anywhere within the ocean basin. This procedure is repeated for a number of potential source locations, chosen according to degree and type of seismic activity. In this way, hypothetical coastal histories of great tsunamis emanating from any potential source area are simulated. The results of this study are offshore incident wave systems and do not include the complex, site-dependent, nearshore transformations. Users must account for such local effects in any specific application.

● 2.6-4 Aida, I., **A source model of the tsunami accompanying the Tonankai earthquake of 1944** (in Japanese), *Bulletin of the Earthquake Research Institute, University of Tokyo*, **54**, *Part 2*, 1979, 329–341.

For the Tonankai, Japan, earthquake of 1944, somewhat different fault models have been proposed by Kanamori (Model I), Ando (Model II), Inouchi and Sato (Model III), and Ishibashi (Model IV). These fault models are examined in this paper from the viewpoint of the tsunami generation, and the optimum model with respect to the tsunami is selected. The tsunami behavior originating from each fault model is computed with the aid of hydrodynamic numerical experiments. The geographic distribution is examined of the ratios of the observed to the computed wave amplitudes for the first and the second half cycles at six tide-gage stations extending over 700 km along the Pacific coast of Honshu and Shikoku. If these ratios do not depend on the locations, then the fault model may be considered to be consistent with the observed tsunami behavior, provided that the magnitude of the fault slip is to be multiplied by the mean value of the ratios.

By means of these procedures, it is found that Model III′ by Inouchi and Sato with the reducing factor 0.45 seems to be the best among the four models. In this model, two fault planes are assumed to strike in the direction of N45°E from the point of 33.08°N and 136.3°E. The first fault encompasses an area 154 km long and 67 km wide and the second fault encompasses an area 84 km long and 78 km wide on the northeastern extension of the first fault. The slip displacements of both faults are given as 2.0 m and 1.4 m for the reversal dip-slip component and 0.7 m and 0.5 m for the left lateral component, respectively. Model III′ with the above reduction gives reasonable ratios between the computed wave height along the 200 m depth contour and the measured runup heights along the coast line of 360 km directly facing the tsunami source area. By means of the detailed computations within the bays, satisfactory agreement of the observed and the computed wave patterns is achieved at Owase Bay which is located near the center of the tsunami source area and in Shimoda Bay which is about 150 km from the margin of the source area. It is concluded that a seismic fault model can be considered a fairly good approximation to the source model for the tsunami generated in the region along the Nankai trough.

● 2.6-5 **Tsunami reports, 1976-26 - 1978-13,** International Tsunami Information Center, Honolulu, Hawaii, 1978, 83.

Tsunami Reports is a series of publications designed to provide information about those seismic events which are thought likely to produce a tsunami. Whenever such an event occurs, the International Tsunami Information Center requests tidal records from appropriate authorities and, after examining the records, a tsunami report is issued. The report shows what records were examined, whether a tsunami was generated and, if so, information about the tsunami is given. This issue contains information for the period from Aug. 16, 1976, to July 23, 1978.

● 2.6-6 Hatori, T., **Behaviors of the Kanto tsunamis of 1677 and 1703 along Kujukuri-hama: from the field investigation of old monuments** (in Japanese), *Bulletin of the Earthquake Research Institute*, 54, *Part 1*, 1979, 147–159.

This paper describes the Genroku tsunami which hit the south Kanto district of Japan on Dec. 31, 1703. Approximately 2150 persons were drowned in villages from Naruto to Ichinomiya along Kujukuri-hama, the open coast of the Boso Peninsula. There are many old monuments in a 30 km region along Kujukuri-hama built just after the tsunami and dedicated to the tsunami victims. The monuments along Kujukuri-hama are illustrated in the paper and, based on the descriptions on the monuments and in other old documents, the behavior of the tsunami is discussed. The topography of the villages along Kujukuri-hama is largely flat. The elevation is 2 to 3 m above the present sea level. During the past 270 years, the beach along Kujukuri-hama has advanced 500 to 600 m by littoral drift. Judging from the distribution of monuments, the tsunami travelled about 3 km inland. The southern region was widely flooded. Inundation heights in the range of 5 to 6 m are inferred.

The Enpo tsunami on Nov. 4, 1677, also hit the region from Iwanuma (Miyagi Prefecture) to the Boso Peninsula. According to old documents, the inundated area of the 1677 Enpo tsunami was narrower than that of the 1703 Genroku tsunami. The inundation height is estimated to be about 4 to 5 m.

2.7 Artificially Generated Ground Motions or Seismic Events

● 2.7-1 Guha, S. K. et al., **Prediction feasibility of induced seismicity following impounding of reservoirs,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1160-1168.

Since the classical case history of seismicity associated with the Lake Mead region in the U.S., about 40 similar incidents have been reported from throughout the world. Of these, only the Koyna (India), Kariba (Zambia), Kremasta (Greece), and Hsinfengkiang (China) events have recorded significant earthquake magnitudes ($M \geq 6.0$) and caused considerable structural damage over a widespread region and to the dams. However, several cases of dam failure caused by seismic phenomena have not been a consequence of induced seismicity but of large amplitude seismic waves originating elsewhere. Other well-documented cases associated with enhanced post-impounding seismic activity are Monteynard (France), Kurobe (Japan), Bileca (Yugoslavia), and Talbingo (Australia). Detailed observations at Nurek Dam (U.S.S.R.) have been undertaken by the U.S.S.R. and the U.S. in collaboration. In spite of the fact that the seismically induced reservoir areas are a small fraction of all the reservoirs, this phenomenon is challenging for earth scientists as well as engineers because of the great potential hazard caused by the impoundment of large bodies of water. An attempt is made to identify parameters closely related to qualitative as well as quantitative prediction of the post-impounding seismic behavior of a reservoir area.

● 2.7-2 Bruce, J. R., Lindberg, H. E. and Abrahamson, G. R., **Simulation of strong earthquake motion with contained explosive line source arrays,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1134-1143.

The results of a two-year investigation demonstrate that the contained explosive line source array is a feasible technique for testing in-situ structures at strong earthquake levels. Tests at one-third scale demonstrate that reasonable amplitudes and frequencies can be coupled into the earth with a minimum of explosives and with no surface eruptions. Theoretical extrapolation to a 100 ft wide by 35 ft deep array shows that 150 lbs of explosive will give a peak velocity of about 15 in./sec, a peak displacement of about 1.5 in., and a fundamental frequency of 3 Hz. The tests also show that repeatable results can be obtained with reuse of the same line sources. Design and testing are now underway to demonstrate that multiple detonations can be fired within a single source, and to simplify construction and improve the performance of the sources. A larger scale single source will soon be designed and tested. Under a new two-year program proposed to begin in early 1980, it is planned to build and test the larger scale, 100 x 35 ft array, consisting of 10 to 12 sources with each source having a 3-pulse-per-test capability. During the first year, the array will be built and tested in the single-pulse mode. In the second year, the 3-pulse-per-test capability will be added. A 30 x 30 ft test area will be available for structural testing. These tests will provide the technological basis for the long-range objective of designing groups of arrays, of this size and larger, that can simulate motions lasting 5 to 10 sec. For example, a group of three arrays of the size described above, with each array adjusted to produce a different pulse duration, could provide a sequence of 18 acceleration pulses (nine detonations) and hence a simulated motion lasting 5 sec and having a frequency content ranging from 2 to 10 Hz. Such arrays could be built after completion of the program described above as a cooperative effort among several universities, or by industrial concerns for use in applied research and immediate application to earthquake resistance certification.

2.7-3 Young, D. and Zurn, W., **Tidal triggering of earthquakes in the Swabian Jura?,** *Journal of Geophysics,* 45, 2, 1979, 171-182.

Several statistical tests were used to investigate the possibility that earthquakes in the Swabian Jura are triggered by the tidal stress in the earth. The results provide limited evidence that the earthquakes tend to occur when the tidal shear stress on the fault plane in the direction supporting the tectonic stress is greatest. A comparison is made of some of the statistical methods available for investigating tidal triggering effects.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 2.7-4 Jacob, K. H. et al., **Tarbela Reservoir, Pakistan: a region of compressional tectonics with reduced seismicity upon initial reservoir filling,** *Bulletin of the Seismological Society of America,* **69,** *4,* Aug. 1979, 1175-1192.

The Tarbela Reservoir is located on the Indus River in the lesser Himalayas of northern Pakistan, a region of considerable natural seismicity. A microseismic survey conducted prior to impounding has indicated that crustal shortening under horizontal north-south compression dominates present-day tectonics, resulting in thrusting and strike-slip motion along numerous faults. The reservoir was first partially filled for a few weeks in 1974 and then completely filled in 1975. In both cases, the microseismic activity decreased slightly during the impounding period and recovered quickly upon commencement of drainage or establishment of a constant reservoir level. In tectonic environments where the maximum principal stress is horizontal and the tectonic system is compressive, a vertical surface load can move the crustal stresses away from Navier-Coulomb failure criterion, and hence, can temporarily decrease seismicity. The observed rapid recovery of seismicity may alternately be explained by: (1) high rates of tectonic strain accumulation which, in turn, increase horizontal stresses at crustal depths; the rates may quickly overcome the stabilizing effects of the small vertical stress changes and increased friction across faults from reservoir loading and, hence, may return the crustal stress system to one of failure; or (2) high diffusivity of the basement rock results in a pore pressure increase after a few weeks of raised reservoir head; the raised pore pressure equally reduces the effective horizontal and vertical stresses and brings the crustal system back to failure. Because direct monitoring of pore pressure at crustal depths is not available at Tarbela, it is not possible to distinguish between the two alternatives. Indirect observations, such as long-term monitoring of space-time changes in seismicity, may aid in the resolution of this ambiguity. A few reservoirs, located in regions with preferentially extensional or pure strike-slip tectonics, have triggered or induced seismic activity, whereas Tarbela Reservoir, in a region of convergent tectonics, has up to the present only slightly modified the natural seismicity. In this region of active Himalayan tectonics, it is likely that the presence of the reservoir will not affect the possibility of a severe earthquake occurring in the near future. Within hundreds of years, a major earthquake near Tarbela appears tectonically inevitable. Yet the presence of the reservoir may strongly affect, say, the time of occurrence, exact location, and the type of rupture of an earthquake. The time most likely for inducing a tectonic stress release (if any) would be during or shortly after a rapid draw-down of the reservoir, when the decrease in pore pressure from its high level at crustal depths lags behind the instantaneous stress decrease caused by reservoir unloading.

● 2.7-5 Lee, K. L., **Subsidence earthquake at a California oil field,** *Evaluation and Prediction of Subsidence,* Paper presented at International Conference on Evaluation and Prediction of Subsidence, American Society of Civil Engineers, New York, 1979, 549-564.

The Wilmington Oil Field in the Long Beach and Los Angeles Harbor areas is the largest of many oil fields in California. Vertical settlement caused by the oil removal has amounted to over 29 ft (10 m) and horizontal movements in excess of 9 ft (2.7 m) have also developed. Millions of dollars of property damage and considerable inconvenience had resulted before the movements were halted by salt-water injection beginning in 1954. An extensive number of articles have been published concerning the subsidence and horizontal movement features at these two oil field areas. Most significantly, from the point of view of this study, are some 5 or 6 small shallow earthquakes which were produced at the Wilmington field during the period of most rapid subsidence. In contrast, no subsidence-induced, shallow-depth earthquakes have been identified from other southern California fields, although these fields were within recording range and hence produced subsidence. For example, the Inglewood field has developed up to 9 ft (2.7 m) of vertical subsidence and 2 ft of accompanying horizontal movement which contributed to the failure of the Baldwin Hills Dam, Dec. 1963, but there have been no earthquakes.

● 2.7-6 Calhaem, I. M., **Pukaki earthquake of 17 December 1978,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, 7-10.

Lake Pukaki is a natural lake in New Zealand. The water level in the lake has been raised twice to provide water storage for power stations constructed or planned for the Upper and Middle Waitaki hydro schemes. The lake was first raised by 9 m in 1955 to a depth of 71.5 m and a volume of about 5 x 10^9 m^3. A second dam, the Pukaki High Dam, completed in 1978, raised the lake an additional 37 m and added 5.5 x 10^9 m^3 to the volume, creating a lake with a maximum depth of 108 m and a volume of more than 10 x 10^9 m^3. In accordance with the recommendation of the "UNESCO Working Group on Seismic Phenomena Associated with Large Reservoirs," the New Zealand Electricity Div. of the Ministry of Energy installed a seismic network around Lake Pukaki comprising one three-component seismometer and eight vertical seismometers. This network has been operating since June 1975.

2.7-7 Martinez, M. L., **Reservoir-associated seismicity** (Vodokhranilishcha i seismika, in Russian), *Gidrotekhnicheskoe stroitel'stvo, 5,* May 1979, 29-31.

The paper reviews world literature on impoundment-induced seismic activity in the construction of large water reservoirs. Dangerous events associated with the Kremasta,

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Kariba, and Koyna dams, and lesser events, including the U.S.S.R. Nurek reservoir problems, are reviewed. Detailed geological studies are required in each particular case to aid in detecting the presence of severely dangerous fissured rocks. Where seismicity is encountered in the course of construction work, it is recommended that the reservoir be filled gradually and with caution to its rated level.

● 2.7-8 Bruce, J. R., Lindberg, H. E. and Abrahamson, G. R., **Simulation of strong earthquake motion with contained-explosion line source arrays: single-source and array tests at camp parks**, SRI International, Menlo Park, California, Dec. 1979, 146.

This report describes the second year of a program to develop a technique which uses explosives to simulate strong level, earthquake-like ground motion. The long-range objective is in-situ testing of soil-structure interaction and of structures with complex internal equipment systems. The technique will be applicable to buildings, nuclear reactors, pipelines, power lines, dams, bridges and tunnels. The technique produces ground motion by simultaneous firing of a planar array of vertical line sources. The controlled release of high-pressure explosion products within each source allows controlled pressurization of the surrounding soil. In this way, both the amplitude and frequency content are controlled at levels suitable for testing with the array close to the test structure. This opens the possibility of in-situ testing at high levels of ground motion with a minimum of explosive and with little disturbance to the surroundings.

During the second year, tests were performed with an array of ten 1/3-scale sources. Tests were also performed with single sources, both in 1/3 scale and full scale. A quasistatic theory was developed to predict both single source and array response. The 1/3-scale array test results, compared to 1/3-scale single source test results, showed a more than order magnitude increase in ground motion. The quasistatic theory predicted this result and compared favorably with both the single-source and array tests. Extrapolation of these results to full scale showed an 80 x 40 ft array can produce accelerations of 0.6 g, velocities of 1 ft/s, and displacements of about 1 in. at frequencies of 3 to 5 Hz, a useful level of ground motion for structural testing.

In a new two-year program proposed to begin in early 1980, tests are planned with a full-scale array. The ability to produce multiple detonations within each source will be added. By the end of the program, the entire array will be tested in a 3-pulse-per-test mode. A 30 x 30 ft test area will be available for structural testing during the program.

● 2.7-9 Asano, S. et al., **Study of change in the velocity of seismic waves in the southern Kanto area by Tateyama explosions** (in Japanese), *Bulletin of the Earthquake Research Institute*, **54**, *Part I*, 1979, 119-134.

Seismic waves generated by explosions of 800 kg of dynamite near Tateyama on the Boso Peninsula in Japan were observed once a year in 1971, 1972, and 1973 at approximately 10 temporary and permanent seismological stations operated by the Dodaira Microearthquake Observatory. The purpose of the experiments was to detect changes in the velocity of seismic waves in the southern part of the Kanto district. Repeat experiments were conducted under not only the same source conditions but also the same observation conditions. Analysis of travel times does not indicate any significant change in the velocity of seismic waves in the period from 1971-1973. However, the data obtained can be used as a basis for future experiments.

● 2.7-10 Rygg, E., **Anomalous surface waves from underground explosions**, *Bulletin of the Seismological Society of America*, **69**, *6*, Dec. 1979, 1995-2002.

The Rayleigh waves at $\Delta \sim 40°$ from an explosion in eastern Kazakh, U.S.S.R., are shown to be polarity reversed and delayed relative to the Rayleigh waves from two other explosions of comparable magnitudes in the same area. The event generating the anomalous Rayleigh waves excited very strong Love waves which were not delayed. The Rayleigh wave phase reversal is shown to be a source phenomenon, and it is suggested that, in this particular case, spall closure was responsible for a major part of the Rayleigh-wave generation.

● 2.7-11 Wu, F. T., Yeh, Y. H. and Tsai, Y. B., **Seismicity in the Tsengwen reservoir area, Taiwan**, *Bulletin of the Seismological Society of America*, **69**, *6*, Dec. 1979, 1783-1796.

The Tsengwen Reservoir, with a maximum depth of 128 m and a storage volume of 708 x $10^6 m^3$, is located over an active thrust fault, the Chuko fault. The Chuko fault was evidently the causative fault of a magnitude 6 3/4 (Pasadena, M_S) earthquake in 1964. Filling of the reservoir started in Apr. 1973 and water reached the designed level in September of that same year; since then, the water level has undergone yearly cycles with 40 to 50 m amplitude. An earthquake swarm occurred near the dam in Dec. 1972 before the filling of the reservoir, and microearthquakes in the area have been monitored for various periods since that time. Before filling, there were some very shallow events, with depths less than 2.5 km, but these disappeared shortly after the water level rose to the maximum. The majority of hypocenters after reservoir loading lie in a layer between depths of 2.5 and 8 km; the seismicity under the reservoir is noticeably lower than that in the surrounding area. There is no obvious correlation of seismicity with water level, based on available data. The seismicity in the Tsengwen area can be described as a response of the overpressured and fractured sedimentary strata to the tectonic stress accumulation, modified by the loading effects of the reservoir. A t_s/t_p versus time study revealed anomalies, but

● *See **Preface**, page v, for availability of publications marked with dot.*

these are not precursory to large earthquakes, as the duration of the anomalies would imply.

2.7-12 Akishin, A. A., Negmatullaev, S. Kh. and Kharin, D. A., **An attempt at simulation of a strong-motion near earthquake by explosions** (O popytke imitatsii vzryvami sil'nogo blizkogo zemletryaseniya, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 191-193.

Multi-row line-source explosive arrays were employed at a test site near Dushanbe, U.S.S.R., to simulate the effects of near-field earthquakes of different magnitudes. Delays between rows and variations in sequencing of detonations were used to simulate different intensities and duration of ground motion, and the response of heavily instrumented 3-story and 4-story structures on the test site was studied.

2.8 Earthquake Prediction

● 2.8-1 Drury, M. J., **Electrical resistivity sounding as a technique for studying crustal dilatancy prior to earthquakes,** *Canadian Journal of Earth Sciences,* **16,** *2,* Feb. 1979, 205-214.

The usefulness of monitoring electrical resistivity changes in a stressed crust as a means of studying crustal behavior during dilatancy prior to earthquakes is considered. Examination of published laboratory data shows that much of the large decrease in resistivity of stressed rocks prior to failure is accounted for by surface conductivity in electrical double layers at rock-fluid interfaces in microcracks. Resistivity changes in the crust might be observed before other dilatancy-induced precursory phenomena are seen because of the strong effect of the surface conductivity. Measurements of resistivity changes alone with time cannot be used for predicting the time of occurrence of an earthquake because of uncertainties in factors such as pore fluid pressure and degree of saturation of newly formed cracks. However, observations of time-dependent resistivity (or impedance) variations might provide information on crustal behavior during dilatancy, because, as cracks begin to open in some preferred direction, the impedance anisotropy of the crust should change. Such changes would be seen in the magnetotelluric impedance tensor elements. Information on crustal behavior during dilatancy is required if a means of predicting the time and location of earthquakes using observations of time-dependent, dilatancy-induced precursory phenomena is to be developed.

2.8-2 Leary, P. C. et al., **Systematic monitoring of millisecond travel time variations near Palmdale, California,** *Journal of Geophysical Research,* 84, *B2,* Feb. 10, 1979, 659-666.

Repeated measurements of *P* wave travel time changes have been completed near the San Andreas fault, 25 km west of Palmdale, California. Spanning a two-yr period beginning in June 1974, the observations were made on 0.1 to 8.5 km base lines and have a worst case accuracy of ± 4 ms. The observation area was centered around Bouquet Reservoir where the *P* wave source, a marine air gun, was secured. The data were taken approximately every five days during June and July 1974, daily from Nov. 1974 to Jan. 1975, and every two hours from Mar. to June 1976. Although the area has undergone regional strain at the rate of $\sim 2 \cdot 10^{-7}$ yr^{-1} during this period, no net *P* wave travel time change greater than 1 part in 10^3 accumulated. Instead systematic and continuous arrival time fluctuations were observed which lasted from hours to days and ranged from 1 to 10 ms. Earth tides and temperature variations, which can produce some signal at diurnal and semidiurnal periods, are at most partially responsible for the observations. The results are interpreted in terms of *P* wave velocity variations in a water-filled cracked medium in which velocity changes are a result of the opening of microcracks during incremental strain. The time scale of anomalous velocity behavior is constrained to be less than the diffusion time of water into newly opened cracks. In this regime, there is little likelihood of detecting long-term earthquake precursors.

● 2.8-3 Rhoades, D. A., **Earthquake forecasting probability charts,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 401-406.

Earthquake forecasts can be expressed in a useful form by mapping the probability that specific levels of shaking will occur within specified time spans. The minimum requirements for a forecasting model are discussed, and an illustration based on the precursory swarm hypothesis is given.

● 2.8-4 Blundell, D., **Geological predictions,** *Disasters,* 3, *1,* 1979, 79-83.

● 2.8-5 Rikitake, T. and Yamazaki, Y., **A resistivity precursor of the 1974 Izu-Hanto-oki earthquake,** *Journal of Physics of the Earth,* 27, *1,* 1979, 1-6.

Close examination of the record of the Yamazaki resistivity variometer in operation at Aburatsubo shows that a precursor-like change began a few days before the May 9, 1974, Izu-Hanto-oki earthquake of magnitude 6.9. This change, which is different from the precursor that occurred four hours before the earthquake, has a resistivity change rate of the order of 10^{-4} and a change in linear strain of 10^{-8}. Similarity among the resistivity change, the change in the maximum amplitude of a volcanic tremor on

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Volcano Mihara, Oshima Island, and the tidal G factor observed at the southern Izu Peninsula is discussed.

● **2.8-6** Bakun, W. H. and McEvilly, T. V., **Are foreshocks distinctive? Evidence from the 1966 Parkfield and the 1975 Oroville, California sequences,** *Bulletin of the Seismological Society of America,* **69,** *4,* Aug. 1979, 1027-1038.

Foreshock activity preceded both the M_L = 5.5 June 28, 1966, Parkfield, and the M_L = 5.7 Aug. 1, 1975, Oroville, California, earthquakes. The *PZ* source displacement amplitude spectrum (0.5 Hz $< f <$ 10 Hz) recorded at Priest Valley, California (Δ = 25 km) for an M_L = 2.6 immediate Parkfield foreshock appears distinctive, characterized by a corner frequency f_0 = 2.5 Hz and an ω^{-1} higher frequency spectral dependence; spectra for another immediate Parkfield foreshock (M_L = 3.1), two nearby Parkfield aftershocks (M_L = 3.0 and 2.9), and three nearby "normal" Parkfield earthquakes (M_L = 2.6, 2.6, and 3.1) are all higher frequency with $f_0 \geq$ 10 Hz. *PZ* and *SZ* signals (0.4 Hz $\leq f \leq$ 10 Hz) recorded at Whiskeytown, California (Δ = 150 km) for an immediate M_L = 3.8 Oroville foreshock have similar corner frequencies ($f_0 \cong$ 2 to 4 Hz) and marginally smaller high-frequency roll-off rates than the corresponding phases for four nearby 3.6 $\leq M_L \leq$ 4.1 Oroville aftershocks; an analogous comparison failed to discriminate an earlier (June 28, 1975) M_L = 3.5 Oroville foreshock from the same five aftershocks. This exercise in attempted foreshock identification, using high-quality data and the two largest central California earthquakes in many years, points up the extreme subtlety of any unique properties in radiated body waves and the resulting difficulty in characterizing foreshocks.

● **2.8-7** Kodama, K. P. and Bufe, C. G., **Foreshock occurrence in central California,** *Earthquake Notes,* **50,** *2,* Apr.-June 1979, 9-20.

The hypocentral regions of 29 (M $\geq$ 3.5) earthquakes along the San Andreas fault system in central California have been systematically examined for increased microearthquake activity preceding the main shock. Of 20 shallow (h $>$ 9 km) main events, 10 were preceded by an apparent buildup of seismic activity. None of 9 deeper (h $<$ 9 km) main shocks was preceded by increased activity. The early buildup of seismicity typically began days to weeks before the main shock and was first followed by a quiet period and then by immediate foreshocks within 24 hours of the main event. Three main shocks with no significant early buildup in the level of seismicity were preceded within 24 hours by single events that, in retrospect, might also be considered foreshocks. Few of the events on the San Andreas fault system examined in this paper were preceded by well-defined foreshock sequences like that associated with the 1975 Oroville earthquake.

● **2.8-8** **Application of space technology to crustal dynamics and earthquake research, draft,** Office of Space and Terrestrial Applications, U.S. National Aeronautics and Space Admin., Washington, D.C., Aug. 1978, 296.

This report presents a plan for the U.S. National Aeronautics and Space Admin. (NASA) research and applications program in crustal dynamics for the period 1980-1985. The goal of this program is to apply space methods and technology to advance scientific understanding of earth dynamics. The plan extends and carries forward the existing NASA programs in geodesy and geophysics and focuses them on two specific objectives. These are, first, to support the U.S. national program in earthquake hazard reduction by studying dynamic processes related to earthquakes; and second, to support the ongoing national and international program of research in global geodynamics. To establish the context in which the NASA activities will be carried out, the objectives of these broader programs are summarized.

● **2.8-9** **The coordinated Federal program for the application of space technology to crustal dynamics and earthquake research,** Office of Space and Terrestrial Applications, U.S. National Aeronautics and Space Admin., Washington, D.C., Jan. 1979, 14.

Discussed in this report are the following topics: review of plate tectonics, relevance of plate tectonics to earthquake hazards and natural resources, the basic issues in earth science, program needs, requirements for space technology, program elements, polar motion and earth rotation, plate stability and relative motion, regional deformation, local strain, and the U.S. National Aeronautics and Space Admin. agency plans and their implementation.

● **2.8-10** **Panel of Experts on the Scientific, Social and Economic Aspects of Earthquake Prediction, Paris, 9-12 April 1979,** *SC-79/CONF.801/2,* Meeting held following the International Symposium on Earthquake Prediction, Paris, 2-6 April 1979, United Nations Educational, Scientific and Cultural Organization and the United Nations Environment Programme, Paris, 1979, 19.

2.8-11 Shakirov, E. Sh., Aralbaev, A. A. and Kim, L. E., **Results of magnetic field ΔZ observations on the Frunze geophysical range** (Rezul'taty nablyudenii magnitnogo polya ΔZ na Frunzenskom geofizicheskom poligone, in Russian), *Geologo-Geofizicheskie Osobennosti i Seismichnost' Territorii Kirgizii,* Ilim, Frunze, U.S.S.R., 1978, 62-65.

Direct confirmation of a relationship between the dynamics of the earth's crust and changes engendered by the crustal displacement in the geomagnetic field is obtained for the first time in practice in the immediate

● *See **Preface**, page v, for availability of publications marked with dot.*

vicinity of the epicenter of the Kochkor earthquake. Regularities in the variation of physical properties of rock in response to a variety of physicochemical and geological factors active at great depths are described. The research is aimed at disclosing direct geomagnetic parameters in the search for earthquake precursors.

● 2.8-12 Hamilton, R., **The earthquake prediction program in the U.S.**, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 41, 6.

An intensive effort to predict the time, place, magnitude, and effects of future earthquakes was undertaken in 1978. Funds for prediction were increased threefold over those in 1977 to about $15,000,000 a year. Expanded programs were also under way in hazards assessment, global seismology, induced seismicity, and engineering. Overall funding for a national program in earthquake hazards reduction exceeds $50,000,000 a year. The U.S. Geological Survey and the National Science Foundation share responsibility for program management. Government, university, and industrial scientists are cooperating in implementing the program. The objectives of the prediction program are to: (1) predict moderate to large earthquakes in time and space and estimate limits of probabilities of the occurrence on the basis of detailed observation; (2) issue earthquake predictions in a timely manner through development of automated data analysis systems; and (3) reduce unreliable predictions of earthquakes through development of a sound understanding of the physical basis for the precursory phenomena observed. Major emphasis in the research studies is on land deformation, seismicity, and physical properties of fault zones. Geochemical, electrical, magnetic, gravitational, stress-strain, and hydrologic phenomena as well as animal behavior are also being studied. Instrumentation is concentrated in areas of high seismicity, including the western United States, Mexico, Central America, New Hebrides, Taiwan, Turkey, and the U.S.S.R.

It is not expected that a quick solution to the prediction problem will be found. Ten years or more may be needed to obtain sufficient observations of precursors to determine the ultimate capability and reliability that could be achieved in a prediction system. A reliable earthquake prediction can save many lives, as has been shown in the People's Republic of China. Preparation for the issuance of predictions must be done to minimize potential negative influences.

2.8-13 Brune, J. N., **Implications of earthquake triggering and rupture propagation for earthquake prediction based on premonitory phenomena**, *Journal of Geophysical Research*, 84, *B5*, May 10, 1979, 2195–2198. (Also in *Proceedings of Conference III—Fault Mechanics and Its Relation to Earthquake Prediction;* see Abstract No. 1.2–14 for complete bibliographic information.)

A simple model of earthquake triggering and rupture propagation based on commonly accepted concepts of earthquake mechanism suggests that earthquake prediction, especially the prediction of magnitude, might be very difficult, depending on the values of certain stress parameters. The concepts embodied in the model suggest areas of research which may help to judge how successful the earthquake prediction effort might eventually be.

2.8-14 Rice, J. R. and Rudnicki, J. W., **Earthquake precursory effects due to pore fluid stabilization of a weakening fault zone**, *Journal of Geophysical Research*, 84, *B5*, May 10, 1979, 2177–2193. (Also in *Proceedings of Conference III—Fault Mechanics and Its Relation to Earthquake Prediction;* see Abstract No. 1.2–14 for complete bibliographic information.)

This paper reports the analysis of two mechanisms by which pore fluids could partially stabilize the earthquake rupture process in natural rock masses. These mechanisms are based on dilatancy strengthening and on the increase of elastic stiffness for undrained as opposed to drained conditions. Both are studied in relation to an inclusion model in which a zone of strain weakening material, possibly representing a highly stressed seismic gap zone, is embedded in nominally elastic surroundings subjected to steadily increasing tectonic stress. Because of the coupling between deformation and pore fluid diffusion, the inclusion does not exhibit an abrupt rupture instability; rather, a period of self-driven precursory creep occurs which ultimately accelerates to dynamic instability. The precursory time scale is reported for a wide range of constitutive parameters, including fluid diffusivity, ratio of undrained to drained stiffness, and factors expressive of strain softening and dilatancy. Among the conclusions are that the precursory times for a spherical inclusion of 1 km radius are of the order of 15-240 days for a range of constitutive parameters suggested as representative. The predicted times are shorter by a factor of approximately 10 for a flattened ellipsoidal inclusion analyzed with an 18:1 aspect ratio. It is suggested that perhaps only toward the latter part of the precursory period are the effects of accelerating inclusion strain detectable in terms of surface deformation or alteration of transport or seismic properties.

2.9 Special Topics

● 2.9-1 Carlson, R., Kanamori, H. and McNally, K., **A survey of microearthquake activity along the San Andreas fault from Carrizo Plains to Lake Hughes**, *Bulletin of the Seismological Society of America*, 69, *1*, Feb. 1979, 177–186.

● *See **Preface**, page v, for availability of publications marked with dot.*

An array of movable seismographic trailers was deployed at three sites along the northern section of the "Big Bend" in the San Andreas fault in southern California. The three sites monitored were the Carrizo Plains, Frazier Park, and Lake Hughes areas. Effective observation times at each site ranged from 38 to 69 days. The microearthquake activity rates observed were 0.3 events/day, 3.0 events/day, and 1.9 events/day, respectively, based on the number of located events plus the number of unlocated events with $S\text{-}P \leq 3.0$ sec. The majority of the activity does not appear to be directly associated with the San Andreas fault. A comparison of the activity rates observed in this study with the results of a survey conducted in the same areas by Brune and Allen indicates more than an order of magnitude increase in activity rate in the Lake Hughes area and nearly the same levels of activity at the Carrizo Plains and Frazier Park sites.

2.9-2 Stierman, D. J. and Kovach, R. L., **An in situ velocity study: the Stone Canyon well,** *Journal of Geophysical Research,* 84, *B2,* Feb. 10, 1979, 672–678.

Velocities of seismic *P*-waves are unusually low in the vicinity of a 600 m deep well drilled into quartz diorite located 1.2 km from the San Andreas fault in central California. These low velocities are attributed to the extensive fracturing of rocks along the fault. Nowhere in the well does the *P*-velocity exceed 70% of the velocity measured in samples of core from the well. Analyses of electrical and gravity logs suggest that saturated macrocracks, while producing only 5-10% porosity, are responsible for the 30-50% reduction of in-situ seismic wave velocities. These macrocracks fail to close in response to confining stress. This is attributed by the authors to dilatancy induced by deviatoric stresses associated with the San Andreas fault, although the possibilities of high pore fluid pressures in the rocks or an increase in fracturing and gouge formation with depth cannot be eliminated. Serious questions are raised concerning the use of laboratory data to model fault zones. In-situ measurements of stress, seismic velocity, and fluid pressures are necessary before we can hope to completely understand the distribution and mechanism of shallow focus earthquakes.

2.9-3 Stuart, W. D., **Strain softening prior to two-dimensional strike slip earthquakes,** *Journal of Geophysical Research,* 84, *B3,* Mar. 10, 1979, 1063–1070.

A model for two-dimensional strike slip faulting in which the fault friction is displacement softening is analyzed to estimate crustal deformation preceding earthquakes and conditions for an earthquake instability. The friction law is initially displacement hardening but becomes softening after the peak stress is surpassed. The peak stress increases with depth to a maximum before decreasing again. The material surrounding the fault is represented by elastic plates. Several deformation histories are calculated by solving numerically the quasi-static, nonlinear problem subject to displacement boundary conditions simulating relative plate motion. When the crust is compliant or the fault is rapidly softening, an inertia-limited instability results. Prior to the instability, the point of maximum fault slip rate moves upward toward the greatest peak stress position. The slip causes a rapid increase in shear strain rate at the free surface near the fault trace. Although fault slip is monotonic, the average fault stress reaches a maximum and then decreases before the instability. When instability is not possible, a similar but smoother deformation episode results. Qualitative extrapolation of the computed results suggests that crustal earthquakes may be preceded by accelerating fault slip near the focus, particularly below the focus, and that the enhanced slip rate may cause recognizable strain and tilt anomalies at the free surface.

● **2.9-4** Yamashita, T., **Aftershock occurrence due to viscoelastic stress recovery and an estimate of the tectonic stress field near the San Andreas fault system,** *Bulletin of the Seismological Society of America,* 69, *3,* June 1979, 661–687.

The possibility of aftershock occurrence resulting from viscoelastic stress recovery after a main shock is discussed theoretically. The tectonic stress field along the San Andreas fault system is estimated using the theoretical results obtained in this study and other theoretical and observational results. The stress gradually rises near the central part of the fault surface if a noticeable primary creep occurs near the fault surface after the main shock and several other tectonic conditions are satisfied. The occurrence of primary creep is probable since the tectonic stress field near the fault plane of the main shock is strongly disturbed. The static frictional stress near the fault plane drops considerably at the time of the main shock, so that aftershocks may be caused by the stress rise. In seismically active areas along the San Andreas fault system, the effective stress (defined as the static frictional stress minus the sliding frictional stress) and the fracture strength (defined as the static frictional stress minus the initial stress) will be very small near the surface of the earth.

● **2.9-5** Nur, A. and Kovach, R. L., **Stochastic vs. deterministic effects in earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1151–1159.

The investigation of the role of heterogeneities in faulting was begun by considering the simplest of all fault models: a rider pulled by an elastic spring. From very simple considerations it was found that heterostress tends to become smoother with increasing slip. This indicates that after some initial heterogeneous sliding fault slip in the model becomes uniform and repetitious, a condition

● *See **Preface**, page v, for availability of publications marked with dot.*

which is clearly not observed in nature. Spatially variable strength, however, can produce and maintain a heterogeneous effective stress. It was found that when strength was sufficiently variable from place to place the final stress was statistically at least as variable as the initial stress. This indicates that the character of fault activity can remain heterogeneous with time, conforming to observed behavior in situ. It is concluded that spatially variable fracture energy may be responsible for the heterogeneous nature of earthquake faulting. Nonuniform stress by itself cannot maintain with time the heterogeneous nature of faults. Allowance for the presence of a free surface by doubling the displacements, velocities, and accelerations computed for an infinite space appears to be valid to within approximately 25%. This conclusion is not generally valid in the case of the residual static displacements. A portion of the near-field coda can be directly attributed to the presence of crustal layers which must be accurately known before precise estimates of source parameters can be made.

● 2.9-6 Stuart, W. D., **Strain-softening instability model for the San Fernando earthquake,** *Science,* **203,** *4383,* Mar. 2, 1979, 907-910.

Changes in the ground elevation observed before and immediately after the 1971 San Fernando, California, earthquake are consistent with a theoretical model in which fault zone rocks are strain-softening after peak stress. The model implies that the slip rate of the fault increased to about 0.1 m per year near the focus before the earthquake.

● 2.9-7 Olsson, R., **Some aftershock sequences in the Japan-Kamchatka region-Part II,** *Report No. 5-78,* Seismological Inst., Uppsala Univ., Uppsala, Sweden, 1978, 26.

Large earthquakes which have occurred during the last 25 years in the areas near Japan, the Kurile Islands, and the Kamchatka Peninsula are the subject of this paper and two previous studies. The present work includes consideration of minor aftershock sequences in the region. There are some common features among sequences which have occurred in the same fault system, most notably a similarity in the magnitude distribution of aftershocks and in the time lapse between significant shocks.

● 2.9-8 Rudnicki, J. W., **The stabilization of slip on a narrow weakening fault zone by coupled deformation-pore fluid diffusion,** *Bulletin of the Seismological Society of America,* **69,** *4,* Aug. 1979, 1011-1026.

The transient stabilization is investigated of rapid slip on a very narrow weakening fault zone by the coupling of the deformation with pore fluid diffusion. More specifically, the fault zone is assumed to be narrow enough so that it can be idealized as a planar surface and the constitutive law is specified as a relation between stress on the fault τ_{flt} and relative slip δ. The study considers only the stabilizing effect resulting from the time-dependent response of the fluid-infiltrated elastic material surrounding the fault: the response is elastically stiffer for load alterations which are too rapid to allow for fluid mass diffusion between neighboring material elements (undrained conditions) than for those which occur so slowly that the local pore fluid pressure is constant (drained conditions). Calculations are performed to determine the length of the precursory period (the period of self-driven accelerating slip prior to dynamic instability) by assuming that the near-peak τ_{flt} versus δ relation is parabolic and that the far-field tectonic stress rate is constant. An important result of the calculations is that the duration of the precursory period is predicted to decrease with increasing fault length for a plausible range of material parameters. Although this appears to disagree with results based on simple dimensional considerations, the result is caused by the dependence of the constitutive law on a characteristic sliding distance necessary to reduce τ_{flt} from peak to residual value. Calculated precursory times are very short, typically less than a few days for fault lengths of 1 to 5 km, a tectonic stress rate of 0.1 bar/year, and field diffusivities of 0.1 to 1.0 m^2/sec. The results are, however, sensitive to details of the τ_{flt} versus δ relation which are, at present, poorly known.

● 2.9-9 Bath, M., **Introduction to seismology,** 2nd, rev. ed., Birkhauser Verlag, Basel, Switzerland, 1979, 428.

This book, a review of modern seismology, presents its historical background, its research methods, and problems of current interest. The book is a translation of *Introduktion till Seismologin.* Included in the volume are a literature review, and subject, author, and geographical indexes.

● 2.9-10 Matumoto, T. and Latham, G., **Distribution of aftershocks following the Guatemala earthquake of 4 February 1976 and its tectonic aspects—interplate and intraplate seismic activity,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 39, 19.

Several thousand earthquakes were recorded by portable seismic stations operated in Guatemala within the first week following the destructive earthquake of Feb. 4, 1976. The seismically active zone followed the Motagua fault through eastern and central Guatemala, and then branched sharply southward about 35 km west of Guatemala City. These data support the conclusion from field evidence that the main earthquake was caused by predominantly left-lateral displacement along the Motagua fault zone. A total rupture length of at least 250 km, defining a segment of the currently active boundary between the North American and Caribbean plates is inferred. Data from the southward trending zone of aftershock activity are consistent with predominantly dip-slip faulting and suggest an intraplate

● *See **Preface,** page v, for availability of publications marked with dot.*

rupture caused within the Caribbean plate. An epicenter plot based on the NEIS earthquake data file suggests additional intraplate activity in a narrow, wedge-shaped portion of the western end of the Caribbean plate. The aftershocks occurring after Apr. 29, 1970, define an elongated zone, approximately 150 km long, trending east-west along latitude 14.5°N. This aftershock zone runs between the volcanic chain of western Guatemala and the axis of the Middle American trench, and may define the westernmost extension of the plate boundary between the North American and the Caribbean plates.

● 2.9-11 Langer, C. J., Bollinger, G. A. and Henrisey, R. F., **Aftershocks and secondary faulting associated with the 4 February 1976 Guatemalan earthquake** (Replicas y fallamiento secundario asociado con el terremoto Guatemalteco del 4 de febrero de 1976, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 42, 25.

A network of portable seismograph stations was used to locate 258 aftershocks of the Feb. 4, 1976, Guatemala earthquake (M_S = 7.5). Although seismic data were obtained over a distance range of approximately 300 km, the field program was designed to concentrate on the aftershock activity at the western terminus of the Motagua fault. Analysis of these aftershock data indicate that several linear or near-linear epicenter trends splay to the southwest away from the end of the causal fault. These trends correlate spatially with mapped surface lineaments and, to some degree, with ground breakage patterns. The observed splaying pattern of aftershock epicenters and the normal-faulting mode of the splay earthquakes, determined from composite focal-mechanism solutions, may be explained by a theoretical pattern of tensile fracturing at the terminus of a strike-slip fault.

● 2.9-12 Dengo, C. A. and Logan, J. M., **Frictional characteristics of serpentinite from the Motagua fault zone in Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 10, 29.

The Motagua fault is similar to other major earthquake-producing strike-slip faults in that they all contain geologically significant amounts of serpentinite; however, uncertainty exists about the behavior of serpentinite. The sliding behavior of five blocks of serpentinite, taken from different locations along the Motagua fault zone, was investigated as a function of confining pressure and composition. The effect of other environmental parameters on the sliding mode of serpentinite was not investigated. This study is intended as a first step towards providing needed laboratory documentation that the frictional behavior of serpentinite is important when this rock type is found along earthquake-generating faults. The study has yielded results which could aid in the understanding of the Motagua and other similar faults.

● 2.9-13 Yamakawa, N., Yoshida, A. and Kishio, M., **Space-time distribution in foreshocks and aftershocks in the Izu-Oshima-kinkai earthquake of 1978—in relation to tectonics in and around the Izu Peninsula** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* 32, *1,* Mar. 1979, 89-101.

The characteristics of the space-time distribution of foreshocks and aftershocks of the Izu-Oshima-kinkai earthquake of 1978 are investigated, and tectonics in and around the Izu Peninsula are discussed. The overall distribution during the period investigated in this research is composed of three parts: group I which spread in the sea near Izu-Oshima, group II which extended to the WNW direction in the Izu Peninsula, and group III which linked with group II at the western end and stretched to the conjugate SSW direction. Among these three groups comparatively large aftershocks occurred in the last group. In groups I and II, aftershocks occurred just after the occurrence of the main shock; in group III, some time appears to have elapsed before the occurrence of earthquakes, though it is not certain when the activity of group III commenced.

The aftershocks of the Izu-hanto-oki earthquake of 1974 which extended to the Amagi Mountain and those of the Oshima-kinkai earthquake of 1978 in the Izu Peninsula do not overlap. In the Izu Peninsula, active faults of the WNW-ESE direction are conspicuous and conjugate faults are also observed. The earthquakes of magnitudes greater than 5.0 which occurred in the Izu Peninsula in the last 50 years are all attributed to the activities of these conjugate fault systems.

● 2.9-14 Kusunose, K., Yamamoto, K. and Hirasawa, T., **Analysis of acoustic emissions in granite under uniaxial stresses for the size relation between microcracks and grains** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* 32, *1,* Mar. 1979, 11-23.

An analysis is made of acoustic emissions occurring while granite specimens (2 cm in diameter and 4 cm in length) were deformed under uniaxial compression. Two kinds of granite are used in the experiment: one is coarse-grained granite with grain sizes between 0.5 mm and 5 mm; the other is fine-grained granite with grain sizes between 0.2 mm and 1.2 mm. The sizes of tensile microcracks, which radiate elastic waves, are determined by solving equations composed of the measured quantity of inelastic volumetric strain and the estimated values of statistical parameters for the frequency-amplitude relationship of acoustic emissions. Based upon the amplitude of events detected with a piezoelectric transducer, the estimated sizes of microcracks range from 0.4 mm to 8 mm for coarse-grained granite and from 0.14 mm to 1.9 mm for fine-grained granite. At low and moderate acoustic emission amplitudes, the observed frequency-amplitude relationship obeys the Ishimoto-Iida formula, but fewer large events occurred than would have been expected theoretically. A critical amplitude appears to exist, and at amplitudes larger than critical, observation deviates from theory. The crack sizes for events with critical amplitudes are found to be about 3 mm for coarse-grained granite and about 0.7 mm for fine-grained granite.

● **2.9-15** Teng, T. L. et al., **Microearthquake monitoring in the City of Long Beach area for the year 1978,** *Technical Report 79-7,* Geophysics Lab., Univ. of Southern California, Los Angeles, July 1979, 50.

This report describes in detail the seismic monitoring work performed for the City of Long Beach. This is the seventh report in a series begun in 1972 which focuses on the seismicity of the Wilmington oil field and the surrounding area. This report covers the period from Jan. 1 to Dec. 31, 1978. One hundred twenty events were recorded and located in the Los Angeles basin area. Of these, there were 27 events with magnitudes between 3 and 5, 86 events between 2 and 3, and 7 events between 1 and 2. No event has been shown to originate within the Wilmington oil field, nor has any detectible earthquake been attributed to fluid injection/extraction operations in the Long Beach area. However, the Newport-Inglewood fault continued to be the focus of several seismic events. Along this fault, some events occurred close to the Dominguez, Long Beach, and Seal Beach oil fields. One epicenter was found inside the Inglewood oil field.

● **2.9-16** Abramovici, F. and Gal-Ezer, J., **Seismic waves from finite faults in layered media,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1693-1714.

The time-dependent solution for a multipolar source in a structure consisting of a homogeneous layer over a homogeneous halfspace is obtained as a sum of generalized rays. Numerical seismograms are calculated for a horizontal strike-slip and a horizontal dip-slip for a point-source, a finite line-source, and a finite two-dimensional source in the form of a rectangle. For comparison, the displacements in a homogeneous space and halfspace are also calculated. The seismograms for finite sources are similar to those for a point-source but show less conspicuous phases, the arriving pulses being wider and less sharp.

● **2.9-17** Acharya, H. K., Ferguson, J. F. and Isaac, V., **Microearthquake surveys in the central and northern Philippines,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1889-1902.

Microearthquake surveys were carried out in three sections of central and northern Philippines during 1975-1976 for a period of 5 months. A 4-month survey of the Bataan Peninsula identified a major tectonic feature near Manila Bay which could not have been postulated from examination of seismicity maps. This feature appears to be situated near the southern end of the ultramafic rocks of west central Luzon and the west Luzon Trough and trends W-SW from east of Corregidor Island toward Manila Trench for a distance of about 100 km. This survey also showed no microearthquake activity beneath two presently inactive volcanoes on Bataan Peninsula. The rate of activity in the Bataan Peninsula region was found to be very low (8.4 events/1000 km^2/yr). A short-duration survey (16 days) of the Philippine fault in North Central Luzon revealed no microearthquake activity on the fault. During a third short-duration survey (16 days), the Verde Island Passage area between Luzon and Mindoro was found to be as highly active at the microearthquake level as it is for large earthquakes.

● **2.9-18** Sakai, A., **A model of fault gouge with dissipative rotational interactions,** *Bulletin of the Disaster Prevention Research Institute,* **29,** *Part 1,* July 1979, 1-25.

This paper describes a model of fault gouge which corresponds to microstructures near a fault plane and discusses preseismic and post-seismic time-dependent deformations and coseismic quasi-elastic deformations in relation to the model.

2.9-19 Skorik, D. A., **Dependence of stability of field of high-frequency microseisms on time and on observation site** (Zavisimost' ustoichivosti polya vysokochastotnykh mikroseism ot vremeni i raiona nablyudenii, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 40-44.

Results of observations of high-frequency microseisms that occurred in various areas of Tadjikistan during 1960-1964 are reported. The observations were recorded by a frequency-selective seismic station. Recording and processing were carried out following a specially developed procedure which eliminates any effect of random noise. The dependence of the stability of the microseismic field on several factors (time, location, and soil conditions) is established.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

3. Engineering Seismology

3.1 General

● 3.1-1 Hasegawa, H. S., Milne, W. C. and Berry, M. J., **Review of seismic attenuation data,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 49–76.

Based primarily upon California data, instrumentally determined measures of anelastic attenuation, which generally lie within 100 km of the epicenter, indicate that (1) peak values of ground acceleration, which predominate at high frequencies, attenuate at approximately the same rate as do peak values of ground velocity, which predominate at intermediate (near 1 Hz) frequencies; (2) the Fourier amplitude spectrum of ground acceleration attenuates approximately linearly with frequency, decreasing with decreasing frequency; and (3) the pseudo-velocity response shows a pronounced minimum at intermediate frequencies. At epicentral distances greater than about 100 km, attenuation measures are, for the most part, based upon intensity data and higher-mode surface waves such as the Lg phase.

For Canada, both intensity data and higher-mode surface waves attenuate at a much slower rate in the east than in the west. Since the tectonic environment of western Canada is similar to that of California, instrumental measures of attenuation in California are applicable to western Canada. The lack of instrumental measures of attenuation in a shield environment, which constitutes much of eastern Canada, requires, at the present time, that the same instrumental data be adopted arbitrarily for the east.

● 3.1-2 Brazee, R. J., **Reevaluation of Modified Mercalli Intensity Scale for earthquakes using distance as determinant,** *Bulletin of the Seismological Society of America,* **69,** 3, June 1979, 911–924.

An assumption is made that the attenuation of earthquake intensity parallels, or is representative of, the dissipation of earthquake energy and thus varies smoothly with distance outward from the center. A model embodying this concept is developed based on 400,000 earthquake intensity elements collected by the U.S. Coast and Geodetic Survey and its successor agencies during the period from 1928 to 1974. Curves for each intensity element of the Modified Mercalli Intensity Scale of 1931 are then derived and fitted to the model. A revised intensity scale is assembled by reassigning the intensity elements in accordance with the results of the fitting process.

● 3.1-3 Wong, H. L. and Trifunac, M. D., **A note on an instrumental comparison of the modified Mercalli (MMI) and the Japanese Meteorological Agency (JMA) intensity scales, based on computed peak accelerations,** *Earthquake Engineering & Structural Dynamics,* 7, *1,* Jan.–Feb. 1979, 75–83.

In many parts of the world, subjectively based earthquake intensity scales similar to those of the modified Mercalli intensity (MMI) are applied regularly. Although the characteristics of these scales are quite similar, it is often difficult to convert an estimate of strong ground shaking measured by the MMI scale into its equivalent on other scales. In this paper, an instrumental correlation of the Japanese intensity scale (JMA) with the MMI scale is described. Currently, one common yardstick that is available for Japan and the United States is the statistic of peak accelerations. The correlation is done by comparing the JMA for sites where the peak acceleration is known in Japan with the MMI for sites in the United States where the peak acceleration also is known. To ensure a direct correspondence of peak accelerations in these two countries, the peak values recorded in the U.S. are corrected by determining the peak acceleration as recorded by the Japanese accelerograph, the SMAC, while it is subjected to the excitation recorded in the U.S.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **3.1-4** Hays, W. W., **A general procedure for estimating earthquake ground motions,** *Engineering Design for Earthquake Environments*, Paper No. C177/78, 67-74. (For a full bibliographic citation, see Abstract No. 1.2-2.)

Specification of earthquake ground motion characteristics for an engineering design application requires careful evaluation of the best available earth sciences and engineering data. From this information, models are developed to estimate ground motion parameters in terms of the seismotectonic province where the earthquake is expected to occur and the frequency-dependent effects of the source of the earthquake and the wave propagation path. Adequate data and fundamental knowledge of the physical processes of earthquakes are the keys to attaining a high level of precision.

● **3.1-5** Omote, S., Miyake, A. and Narahashi, H., **Estimations of the earthquake force appeared in an epicentral area in the case of large destructive earthquake,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering*, New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 33-52.

Evaluation of the maximum ground acceleration in the 1975 Oita, Japan, earthquake was made from field surveys of overturned gravestones. Applying this method to some earlier earthquakes, the relation between maximum acceleration and magnitude of an earthquake was derived. Comparing this result with the peak value of maximum accelerations observed in the strong-motion seismogram, the authors obtained excellent agreement.

● **3.1-6** McGuire, R. K. and Barnhard, T. P., **The usefulness of ground motion duration in predicting the severity of seismic shaking,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 713-722.

The duration of strong ground motion has long been considered important in assessing the severity of seismic shaking, because peak amplitudes of the motion do not fully describe all observed characteristics of seismically induced shaking. In particular, it is believed that long-duration ground motion is more damaging than short-duration ground motion with the same peak acceleration. An example, showing two accelerograms recorded at El Centro, California, is presented; the records indicate approximately the same peak acceleration and velocity, but the first record (a "pulse-type" motion) is generally considered to be of shorter duration and therefore less damaging than the second record (a "vibratory" motion).

A probabilistic seismic hazard map has been published for the United States which shows peak horizontal acceleration for a specified probability level, and additional maps are planned for other peak motion parameters. The suggestion has been offered that the duration of strong shaking should be mapped as well, in order to better define the seismic hazard. The purpose of this research is to examine several quantitative definitions of duration which have been proposed and to determine with what accuracy strong-motion duration can be predicted, and which definitions are useful, in addition to peak motion parameters, for specifying the severity of seismic shaking. In the context of current procedures used to map ground motion, it is assumed that only magnitude and distance representations of the source and travel path are used and that the only available characteristics of the motion (in addition to duration) are peak amplitudes.

● **3.1-7** Chung, D. H. and Bernreuter, D. L., **On the regionalization of ground motion attenuation in the conterminous United States,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 753-762.

Attenuation results from geometric spreading and from absorption. The former is almost independent of crustal geology or physiographic region. The latter depends strongly on crustal geology and the state of the earth's upper mantle. Except for very high-frequency waves, absorption does not affect ground motion at distances less than 25 to 50 km. Thus, in the near-field zone, the attenuation in the eastern United States will be similar to that in the western United States. Most of the differences in ground motion can be accounted for by differences in attenuation caused by differences in absorption. The stress drop of eastern earthquakes may be higher than for western earthquakes of the same seismic moment, which would affect the high-frequency spectral content. However, the authors believe that this factor is of much less significance than differences in absorption in explaining the differences in ground motion between the eastern and western United States.

● **3.1-8** Mortgat, C. P., **A probabilistic definition of effective acceleration,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 743-752.

This paper presents a definition of effective acceleration based on the probability of a number of excursions beyond different levels of acceleration during an earthquake. An exponential distribution is fitted to the peaks of the time history after the peaks are put into ascending order. A stable parameter that correlates peak amplitude and root-mean-square acceleration is given.

● **3.1-9** Kameda, H. et al., **Prediction of nonstationary earthquake motions for given magnitude, distance, and**

● *See **Preface**, page v, for availability of publications marked with dot.*

specific site conditions, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 243–252.

A statistical prediction model is developed for generating nonstationary earthquake motions for given values of magnitude and distance and for soil conditions at specific sites. The model has been verified for use in analyzing inelastic structural response. Statistical uncertainty of the model parameters is incorporated to give a rational basis for engineering evaluation. Applicability of the proposed model to a wide frequency region enables the model to be used for generation of ground acceleration, velocity, and displacement values.

● **3.1-10** Das, S. and Richards, P. G., **Effects of nonuniform spontaneous rupture propagation on the level and duration of earthquake ground motion,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 203–212.

The most complete information that seismologists can give engineers studying earthquake hazards for various structures concerns the time histories of ground displacement, velocity, and acceleration. The ground motion at a site is a space-time convolution of the earthquake source-time function and the impulse response of the medium between the earthquake epicenter and the site of the structure. Discussed is the effect of nonuniform rupture propagation on the source-time function and on the resulting ground motion.

● **3.1-11** Sandi, H., **Measures of ground motion,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 263–272.

It is the objective of this paper to contribute to the development of more suitable concepts and techniques related to the measurement of local ground motion and the effects of earthquakes. The approach adopted is intended to better suit the engineering needs of accuracy and flexibility and is basically empirical from a seismological viewpoint.

● **3.1-12** Blume, J. A. and Kiremidjian, A. S., **Probabilistic procedures for peak ground motions,** *Journal of the Structural Division, ASCE,* **105**, *ST11,* Proc. Paper 14976, Nov. 1979, 2293–2311.

Three methods for estimating the frequency of earthquake occurrence are presented: regression analysis of past earthquake data; integration of fault-dislocation data over long time periods; and consideration of plate boundary dislocation rates. The models consider fault rupture as a function of magnitude when faults can be modeled as line sources. When locations and activity rates are not known, seismically active regions are modeled as diffused area sources. The equation for attenuation of ground motion includes a soil impedance factor and a lognormal probability distribution on the data scatter. By applying the three procedures to a site for a nuclear power plant in southern California, it was determined that the plate boundary method yields lower peak ground motion values than the other methods at the same risk level. The highest peak ground acceleration values were predicted by the long-period (20,000,000 yr) fault-dislocation method.

● **3.1-13** Trifunac, M. D. et al., **Methods for prediction of strong earthquake ground motion,** Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, May 1979, 573.

This report summarizes the work accomplished on the characterization of strong earthquake ground motion for use in seismic risk studies, development of modern standards and regulatory guides, reevaluation of existing sites, and development of site-specific criteria for earthquake-resistant design. The detailed theoretical analyses, data-handling methods, and computer programs are presented in appendixes.

● **3.1-14** Jennings, P. C. and Kanamori, H., **Determination of local magnitude, M_L, from seismoscope records,** *Bulletin of the Seismological Society of America,* **69**, *4,* Aug. 1979, 1267–1288.

A method is presented for determining the local magnitude, M_L, from records from seismoscopes and similar instruments. The technique extrapolates the maximum response of the standard Wood-Anderson seismograph, which determines M_L, from the maximum response of the seismoscope. The standard deviation of the steady-state response of an oscillator subjected to white noise excitation is used to derive a relation, correcting for the different periods, dampings, and gains of the two instruments. The accuracy of the method is verified by application to data from the San Fernando and Parkfield earthquakes for which both accelerograph and seismoscope records are available from the same sites. The accelerograms are used to synthesize Wood-Anderson responses whose maxima are compared to those extrapolated from the seismoscope data. In both earthquakes, the average magnitudes and standard deviations determined by the two approaches are very nearly equal.

The method is then applied to the strong-motion data from the Managua, Nicaragua earthquake of Dec. 23, 1972 (M_S = 6.2, m_b = 5.6). A value of M_L = 6.2 is indicated from the seismoscope and accelerograph data. The next application is to the Guatemala earthquake of Feb. 4, 1976 (M_S = 7.5, m_b = 5.8). The only seismic instrumentation available for determining M_L is a seismoscope record from

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

Guatemala City, which indicates M_L = 6.9 when a representative distance of about 35 km is used. As a final example, the records obtained during the 1906 San Francisco earthquake (M_S = 8 1/4) from the Ewing duplex pendulum seismograph at Carson City, Nevada, and the simple pendulum at Yountville, California, are analyzed. After restoring the Carson City instrument, its period and damping were determined experimentally as were the period and damping of a similar instrument in the London Science Museum. On the basis of the strong-motion records from Carson City and Yountville, it is estimated that the local magnitude of the 1906 earthquake lies in the range 6 3/4 to 7.

The use of seismoscope data further extends the instrumental base from which M_L can be determined and allows the rapid determination of M_L in earthquakes where seismoscope data are available. The applications in this study provide further instrumental evidence for the saturation of M_L in the 7 to 7 1/2 range, with the value of 7.2 for the Kern County earthquake of 1952, the largest so far determined.

● **3.1-15** Miyamura, S., **Magnitude of earthquakes (I),** *IISEE Lecture Notes 11,* International Inst. of Seismology and Earthquake Engineering [Tokyo], 1978, 83.

This report defines and discusses earthquake magnitudes. Topics covered include (1) local magnitude as originally defined by Richter (1935) and later extended by Gutenberg and Richter (1942); (2) the extension of the magnitude scale to teleseismic distance by Gutenberg and Richter (1936) and Gutenberg (1945); (3) the introduction of the concept of body wave magnitude by Gutenberg (1945); (4) magnitude studies conducted in the 1950s and early 1960s by researchers other than Gutenberg and Richter; and (6) inconsistencies among different magnitude values. Also included is a bibliography of literature published on the subject from 1913–1967.

● **3.1-16** Lai, S.-S. P., **Ground motion parameters for seismic safety assessment,** *Seismic Safety of Buildings, Internal Study Report 17,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Feb. 1979, 68.

A set of 140 strong earthquake records is used to assess uncertainties involved in ground motion representation for the purpose of seismic analysis and design. In particular, the characterization of seismic input in terms of a power spectral density (PSD) function is studied. Based on the moments method of fitting a PSD spectrum, parameters of the Kanai-Tajimi power spectral density function are determined for a set of records. Statistics and probability distributions for strong-motion duration, Kanai-Tajimi frequency, and damping coefficients are computed. The interdependencies of these seismic parameters are also investigated.

Correlation studies of strong-motion duration, central frequency, Kanai-Tajimi frequency, and damping coefficient versus earthquake peak ground acceleration, epicentral distance, and local magnitude are performed. Several interesting correlation relationships of pertinent seismic parameters are suggested. The results reported provide an understanding of the variability of ground motion representation. Moreover, the findings provide a sound basis for characterizing seismic input for overall seismic safety assessment.

● **3.1-17** Ohsaki, Y., **On the significance of phase content in earthquake ground motions,** *Earthquake Engineering & Structural Dynamics,* 7, 5, Sept.–Oct. 1979, 427–439.

A number of problems relating to characteristics of harmonic phase angles contained in earthquake ground motions are discussed in this paper. These problems of harmonic phase angles have not received the attention given to harmonic amplitudes. Particularly emphasized is the significance of the concept of phase differences in certain properties of earthquake ground motions. Several applications of this new concept to earthquake engineering problems are illustrated.

● **3.1-18** Gurpinar, A. et al., **Attenuation relationships for western Anatolia,** *Report 78-03,* Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, Aug. 1978, 15.

Attenuation relationships are derived for western Anatolia. The procedure used to derive the relationships does not require instrumental data but does require observations in the form of isoseismal maps from which attenuation relationships can be developed for intensity. Intensities can then be converted to some other ground motion parameter, such as the peak ground acceleration, through available relationships.

● **3.1-19** Nuttli, O. W., **The relation of sustained maximum ground acceleration and velocity to earthquake intensity and magnitude,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 16,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Nov. 1979, 100.

Sustained maximum ground acceleration and velocity are measures of the strongest prolonged, rather than peak, acceleration and velocity. In this report, the sustained maximum ground acceleration, velocity, and duration are given for the accelerograms contained in the California Inst. of Technology collection, Parts A-Y. Correlations are

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

presented between sustained maximum acceleration, velocity, and the product of acceleration and duration versus MM intensity. In order to compare western United States earthquakes with earthquakes occurring in other parts of the world, relations are developed between the local and Richter magnitude scales and the more universal body-wave and surface-wave magnitude scales. The fall-off of ground acceleration and velocity as a function of distance from the fault rupture and body-wave magnitude is determined for western United States, coastal California and central United States earthquakes. The logarithm of the sustained maximum acceleration is shown to scale as 0.5 times the body-wave magnitude, and the logarithm of the sustained maximum velocity is shown to scale as the body-wave magnitude. The vertical components of ground acceleration and velocity are found to have very nearly one-half the amplitude of the larger of the two horizontal components of strong ground motion for western United States earthquakes. On the average, the peak ground acceleration is found to be 1.4 times the sustained maximum (3 cycles) ground acceleration, and the peak ground velocity 1.75 times the sustained maximum (3 cycles) ground velocity. The semi-empirical equations developed in this report can be used to estimate ground acceleration, velocity, and duration at a site if the earthquake magnitude and distance from the fault rupture are known, and/or if the site MM intensity is known.

● 3.1-20 Fiedler, G., **Relations between magnitude and ground acceleration for long distance earthquakes,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 49, 8.

The Pasadena magnitudes (M. PAS.) of earthquakes with epicentral distances more than 2500 km from Caracas, Venezuela, are compared with the vertical ground acceleration recorded by the Gravity Earthtide Station of the Seismological Inst. at Caracas. Exponential relations are found.

● 3.1-21 Idriss, I. M. and Akky, M. R., **Primary variables influencing generation of earthquake motions by a deconvolution process,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/3, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents the results of a parametric study conducted to examine the accuracy, convergence, and stability of a frequently used deconvolution process and the significant parameters that may influence the output of this process. Parameters studied included: soil-profile characteristics, input motion characteristics, level of input motion, and frequency cutoff. The results of the parametric study and examination of the theoretical formulation of the deconvolution process indicate the following: (1) The results of a deconvolution analysis are controlled by the transfer function between the input level and the level at which the response is being calculated. (2) The transfer function is affected mainly by the following factors: (a) the dynamic characteristics of the soil deposit under consideration, (b) the level at which the input motion is specified, (c) the characteristics of the input motion, and (d) the highest frequency (i.e., frequency cutoff) included in the computations. (3) The effects of the factors listed above are interdependent. In particular, the results of the cases analyzed as part of this study and other cases emphasize the need for careful specification of the input motion and the depth at which the motion is imposed.

● 3.1-22 Acharya, H. K., **Regional variations in the rupture-length magnitude relationships and their dynamical significance,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979. 2063-2084.

Regional relationships between earthquake magnitude and rupture length have been determined for different parts of the world based primarily on aftershock data. It appears from this study that a given rupture corresponds to an earthquake of different magnitude in different regions. The correlation between rupture length and magnitude is high for each region, and the noted scatter in such data for a given rupture is consistent with separation between extremes. This suggests that the scatter in worldwide data may be a result of regional differences. Assuming that stress and stress drop are constant, the regional difference in magnitude for a given rupture can be interpreted in terms of regional variation in seismic efficiency. Furthermore, the data suggest that seismic efficiency in a region is dependent on rupture length or magnitude.

● 3.1-23 Anderson, J. G., **A comment on the relationship between earthquake magnitude and rupture length,** *Earthquake Notes,* **50,** 2, Apr.-June 1979, 3-8.

There is a physical basis for the existence of scatter in relationships between the magnitude and rupture length of earthquakes. This article suggests that, when such a relation is applied to estimate the maximum magnitude which may occur on some fault, a relationship which bounds the existing data is most appropriate. For a probabilistic risk analysis, it is better to use a physically motivated description of the scatter of rupture lengths; one way to do this is by introducing the stress drop.

● 3.1-24 Espinosa, A. F., **Horizontal particle velocity and its relation to magnitude in the Western United States,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 2037-2061.

A magnitude (M_L) scaling law has been derived from the strong-motion data base of the San Fernando earthquake of Feb. 9, 1971, and the results have been compared with other strong-motion recordings obtained from 62 earthquakes in the Western United States. The relationship derived is $M_L = 3.21 + 1.35 \log_{10}\Delta + \log_{10}v$. An excellent agreement was obtained between the determined M_L values in this study and those evaluated by Kanamori and Jennings. This scaling law is applicable to the collected data from 63 earthquakes whose local magnitudes range from about 4.0 to 7.2, recorded at epicentral distances between about 5 to 300 km, and with short-period seismic waves in the range of 0.2 to 3.0 sec. The Long Beach earthquake of 1933, with an $M_L = 6.3$ (PAS) and an $M_L = 6.43 \pm 0.36$ as determined by Kanamori and Jennings is in agreement with an $M_L = 6.49 \pm 0.32$ obtained in this study. The Imperial Valley earthquake of 1940, with an $M_L = 6.5$ (PAS), compares well with an $M_L = 6.5$ as determined in this study. The Kern County earthquake of 1952, with an $M_L = 7.2$ (BRK), is in fairly good agreement with the $M_L = 7.0 \pm 0.2$ obtained in this investigation. This value is significantly lower than the commonly quoted 7.7 value for this event. The San Francisco earthquake of 1957, with an $M_L = 5.3$ (BRK), agrees very well with an $M_L = 5.3 \pm 0.1$ as determined in this study. The Parkfield earthquake of 1966 has an $M_L = 5.8 \pm 0.3$, which is consistent with the 5.6 (PAS). The procedure developed here is applied to the data base obtained from the Western United States strong-motion recordings. The procedure allows the evaluation of M_L for moderate and larger earthquakes from the first integration of the strong-motion accelerograms and allows the direct determination of M_L from the scaled amplitudes in a rapid, economical, and accurate manner. It also has allowed for the extension of the trend of the attenuation curve for horizontal particle velocities at distances less than 5 km for events of different sizes.

● **3.1-25** Chandra, U., **Attenuation of intensities in the United States,** *Bulletin of the Seismological Society of America,* **69**, *6*, Dec. 1979, 2003-2024.

Isoseismal maps for a number of earthquakes were analyzed to study the attenuation of intensities with distance for different regions of the United States. A graphical method for the estimation of an initial set of epicentral intensities, I_0, from the intensity-distance plot for different earthquakes was used, thus avoiding the need to equate the maximum reported or mapped intensity with I_0. The attenuation relations were derived by using an iterative least-squares fit procedure, wherein an initial approximate estimate of I_0 for each earthquake is successively improved. As a by-product, the analysis yielded improved estimates of I_0 for each earthquake. These I_0 values were used to derive empirical relations between felt area and epicentral intensities for different regions.

● **3.1-26** Bloom, E. D. and Erdmann, R. C., **Frequency-magnitude-time relationships in the NGSDC earthquake data file,** *Bulletin of the Seismological Society of America,* **69**, *6*, Dec. 1979, 2085-2099.

In performing a statistical analysis of the National Geophysical and Solar-Terrestrial Data Center (NGSDC) data base, the authors have found that the time and magnitude data are incomplete. This lack of information can affect the accurate determination of derivative frequency-magnitude relations. Techniques are suggested which may circumvent most inaccuracies. In particular, the choice of event magnitude is important in minimizing distortion in frequency-magnitude relations. A new working magnitude, M_3, is suggested as useful for the NGSDC data base. After correcting for time bias, the use of M_3 reduces distortion of frequency-magnitude distributions derived from the NGSDC data base as compared to previous magnitude definitions used.

● **3.1-27** Street, R. L., **An instrumental m_{bLg} magnitude estimate of the 1897 Giles County, Virginia, earthquake,** *Earthquake Notes,* **50**, 2, Apr.-June 1979, 21-23.

On May 31, 1897, an epicentral intensity VII-VIII modified Mercalli (MM) earthquake was felt over an area extending north-south from northern Ohio to central Georgia and east-west from the Atlantic coast to western Kentucky. Based on intensity reports, the earthquake is believed to have been centered near the town of Pearisburg in Giles County, Virginia. The felt area of the event encompassed 735,000 km^2, while the MM intensity IV isoseism of the event encompassed 351,000 km^2. Based on a slightly greater felt area estimate (895,000 km^2), the area within the intensity IV isoseism, and the fall off-of-intensity technique developed by Nuttli for estimating m_b magnitudes, Nuttli et al. calculated m_b magnitudes of 5.2, 5.8, and 5.8, respectively.

3.1-28 Medvedev, S. V., **Determination of earthquake intensity** (Opredelenie intensivnosti zemlyetryasenii, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 108-116.

An improved variant of a scale for classifying earthquake phenomena is proposed, with values of accelerations, velocities, and displacements increased by roughly a factor of one and a half over the MSK-64 scale. Categories relating to the extent of damage to buildings and structures and various other changes (reactions by humans and animals, disturbance of surface and subsurface features) are introduced.

● **3.1-29** Shannon & Wilson, Inc., and Agbabian Assocs., **Statistical analysis of earthquake ground motion parameters,** *NUREG/CR-1175,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Dec. 1979, 183.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

Several earthquake ground response parameters that define the strength, duration, and frequency content of the motions are investigated using regression analysis techniques; these techniques incorporate statistical significance testing to establish the terms in the regression equations. The parameters investigated are the peak acceleration, velocity, and displacement; Arias intensity; spectrum intensity; bracketed duration; Trifunac-Brady duration; and response spectra amplitudes. The study provides insight into how these parameters are affected by magnitude, epicentral distance, local site conditions, direction of motion (i.e., whether horizontal or vertical), and an earthquake-type event. The results are presented in a form that should facilitate their use in the development of seismic input criteria for nuclear plants and other major structures. The results are compared with results from investigations that have been used in the past in developing criteria for such facilities.

3.2 Strong Motion Records, Interpretation, Spectra

● 3.2-1 Hartzell, S., **Analysis of the Bucharest strong ground motion record for the March 4, 1977 Romanian earthquake**, *Bulletin of the Seismological Society of America*, 69, 2, Apr. 1979, 513–530.

The major features of the Bucharest strong ground motion record for the Mar. 4, 1977, Romanian earthquake can be explained with a source at a depth of 100 km which propagates to the southwest, toward Bucharest, with a rupture velocity near the shear-wave velocity. Rayleigh-wave amplitudes from SRO, HGLP, and WWSSN stations yield a moment estimate in the range 1.0 to 2.0 X 10^{27} dyne-cm, after correction for a moving source and averaging over 13 stations. The Bucharest strong ground motion record shows a peak acceleration of 221 cm/sec^2 (in the period range from 1 to 2 sec) and a peak displacement of 27 cm on the NS component at a hypocentral distance of 190 km. Both line source models in a homogeneous halfspace and single and multiple event source models in a layered halfspace are used to analyze the Bucharest record. The relatively simple form and high amplitudes of the Bucharest accelerogram are attributed to the small epicentral distance to source depth ratio and the low rigidity flysch sediments in the Bucharest area. The relative amplitudes on the three components of the Bucharest record suggest that the rupture plane steepened after the initial break from a dip of 70° to an approximately vertical orientation. However, other factors may also be important, such as near source or receiver heterogeneity or the bending of rays by the subducting lithospheric plate under the Carpathian arc. The moment estimate from the Bucharest accelerogram is 2.0 X 10^{27} dyne-cm. Using the above moment estimate and assuming a circular fault plane with a radius of 25 km, the author estimates the average offset to be 1.5 m with a stress drop of 57 bars.

● 3.2-2 McCann, Jr., M. W. and Shah, H. C., **Determining strong-motion duration of earthquakes**, *Bulletin of the Seismological Society of America*, 69, *4*, Aug. 1979, 1253–1265.

The duration of strong ground motion is widely recognized as an important characteristic affecting the response of man-made structures. The basis of this study is to define strong-motion duration in a manner consistent with the use of the root-mean-square acceleration as a ground-motion parameter. The root-mean-square and duration give a good measure of the strong-motion intensity. The dependence of the root-mean-square on duration is studied through the use of the cumulative RMS (root-mean-square) function. The rate of change of the RMS is obtained by taking the derivative of the cumulative RMS function. The derivative identifies the time after which the RMS is always decreasing. This time value is used as the upper cutoff time (T_2) in defining the significant duration (T_2 - T_1). The lower cutoff time (T_1) is found by performing the above operation on the record with a reversed time scale. Results for the horizontal components of 30 strong-motion earthquake records are presented with the RMS for the defined strong motion. Comparisons of strong-motion duration, as defined by the methods of Trifunac-Brady, Bolt, and Vanmarcke and Lai, and the proposed method are presented. The use of the root-mean-square acceleration as a ground-motion parameter is also discussed.

● 3.2-3 Trifunac, M. D., **Preliminary empirical model for scaling Fourier amplitude spectra of strong ground acceleration in terms of modified Mercalli intensity and recording site conditions**, *Earthquake Engineering & Structural Dynamics*, 7, *1*, Jan.–Feb. 1979, 63–74.

This paper presents an empirical model for scaling Fourier amplitude spectra of ground acceleration during strong earthquake shaking in terms of the reported modified Mercalli intensity (MMI) and the simplified characteristics of the geologic environment at the recording station. This analysis shows that: (1) for the intermediate and high-frequency motions the spectral amplitudes approximately double for every level of the MMI; (2) the uncertainties associated with estimation of Fourier spectral amplitudes in terms of MMI are not greater than the uncertainties associated with similar estimation in terms of earthquake magnitude and epicentral distance; (3) the high-frequency spectral amplitudes tend to be greater on basement rock sites relative to alluvium sites, with this trend being reversed for the low-frequency spectral amplitudes; and (4) the spectral amplitudes of very high-frequency vertical shaking are equal to or higher than the corresponding spectral amplitudes for horizontal shaking.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 3.2-4 Iyengar, R. N. and Rao, P. N., **Generation of spectrum compatible accelerograms,** *Earthquake Engineering & Structural Dynamics,* 7, 3, May-June 1979, 253-263.

This paper presents a new method for generating earthquake accelerograms which have preestablished response spectra. The nonstationary random nature and other salient features of the accelerograms can be accommodated by the procedure developed. The method leads to a sample spectrum which lies above the given spectrum. The generation of records to suit several spectra simultaneously also can be managed by this approach. The method is described and several numerical examples are given.

● 3.2-5 Medearis, K., **Dynamic characteristics of ground motions due to blasting,** *Bulletin of the Seismological Society of America,* **69**, 2, Apr. 1979, 627-639.

There is considerable evidence that more rational damage criteria need to be generated for lowrise structures subjected to seismic ground motions. There is not sufficient basis for specifying a maximum ground particle velocity criterion, such as 2 in./sec. A peak ground velocity guideline does not currently take into account a number of important parameters, including the predominant frequencies of the ground motion excitation and the structure being excited. Although a number of states have adopted peak-velocity criteria, such criteria have been ruled inadequate in certain legal decisions affecting blasting operations. The development of more rational damage criteria is thus of significant importance. Such criteria must necessarily consider the dynamic characteristics of seismic ground motions, i.e., pertinent and dominant frequency characteristics, response and Fourier spectra, etc. Very little analysis has been done with regard to determining the dynamic characteristics of blasting ground motions, however.

This paper describes a research effort concerned with the determination of these characteristics for a sizeable number of actual blasting records using appropriate theoretical and computer analyses. Peak ground motion versus charge and distance relationships were derived, as well as pertinent response spectra. Statistical representations of the latter were also obtained using 200 ground motion records.

● 3.2-6 Bentley, R. J., **Average estimates of the attenuation with distance of 5% damped horizontal acceleration response spectra,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 553-568.

Five percent damped horizontal acceleration response spectra from 98 earthquakes (135 strong-motion spectra) are collated in 24 separate magnitude and epicentral distance groupings. Average spectra are calculated for hard and soft site conditions. Average attenuation relationships for peak acceleration response over the range of 0 to 3 sec are constructed for a region outside the western United States. For a particular site where the seismicity is specified, five percent damped response spectra are constructed for varying return periods. It is suggested that spectra for design at that particular site can be obtained on a more rational basis (for example, by setting acceptable risks of structural damage) than is used in traditional design codes.

● 3.2-7 Zsutty, T. and De Herrera, M., **A statistical analysis of accelerogram peaks based upon the exponential distribution model,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 733-742.

In seismic-resistant design of structures and foundation systems, it is essential to have a knowledge of the cyclic load reversal capabilities of a specified earthquake ground motion. The commonly used parameters of maximum peak ground acceleration and the acceleration response spectrum are inadequate for the description of these load cycles in terms of numbers of peaks; therefore, current research is involved with the evaluation of effective duration and RMS values in order to better fulfill the needs of the design process. Clearly, the most descriptive load input would be the exact acceleration time history for a given design event; however, this is impossible to prescribe either in terms of selected past records, or in the form of generated artificial records or even random process models, unless some information is available concerning the number and value distribution of the family of peaks corresponding to the design event.

This paper presents a statistical procedure for the estimation of this peak number and value distribution from available strong-motion time histories. The method to be employed differs from current procedures involving effective duration, RMS values, and related random vibration models; the goal is to provide efficient estimates of the type of distribution and its parameters for the family of acceleration peaks.

● 3.2-8 Hays, W. W., Rogers, A. M. and King, K. W., **Empirical data about local ground response,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 223-232.

This paper presents results of research on local ground response obtained from analysis of broadband ground-motion data recorded from earthquakes and nuclear explosions. The results are given in terms of transfer functions, which are defined as the average ratio of the five-percent damped, horizontal response spectra for a pair of sites. Although the subject is controversial and relevant empirical data are still limited, a number of questions concerning ground response are addressed, including: (1) How similar

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

are transfer functions derived from earthquake and nuclear-explosion ground motions? (2) Over what range of ground-motion and strain levels can the transfer function be repeated and remain essentially unchanged? (3) What variance is associated with the mean transfer function? (4) What physical parameters control the horizontal and vertical spatial variation of ground response in an area?

● 3.2-9 Porcella, R. L. and Matthiesen, R. B., **Preliminary summary of the U.S. Geological Survey strong-motion records from the October 15, 1979 Imperial Valley earthquake,** *Open-File Report 79-1654,* U.S. Geological Survey, Menlo Park, California, Oct. 1979, 41.

This report summarizes the data from near-in strong-motion accelerograph stations operated by the U.S. Geological Survey in the Imperial Valley of California at the time of the Oct. 15, 1979, Imperial Valley earthquake. A similar preliminary report of strong-motion data collected by the Office of Strong-Motion Studies of the California Div. of Mines and Geology has already been issued (see Abstract No. 3.2-10). A more complete report of the strong ground motion data, requiring the cooperation of all of the agencies in the U.S. and Mexico that operate strong-motion instruments in the region, is contemplated. A report on the processing of the data from near-in stations is in preparation.

● 3.2-10 California, Office of Strong Motion Studies, **Preliminary data: partial film records and file data-Imperial Valley earthquake of 15 October 1979,** Sacramento, 1979, 18.

For a summary of the U.S. Geological Survey strong-motion records from the Imperial Valley earthquake, see Abstract No. 3.2-9.

● 3.2-11 Ishida, K., **An approximate method for estimating the strong motion earthquake spectra on bedrock,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 273-282.

The variation of an observed spectrum from a theoretical spectrum in the short-period range is estimated and defined by an equation. An approximation of the attenuation effect of the wave path is considered. The equation gives an indication of the effect of the stick-slip phenomenon along the fault plane. Strong-motion records used for the study are from the 1966 Matsushiro earthquake swarm and from the 1966 Parkfield and the 1968 Tokachi-oki earthquakes.

● 3.2-12 Hudson, D. E., **Reading and interpreting strong motion accelerograms,** *Engineering Monographs on Earthquake Criteria, Structural Design, and Strong Motion Records,* Earthquake Engineering Research Inst., Berkeley, California [1979], 112.

This book provides the nonspecialist in strong-motion earthquake instrumentation and data processing with the basic knowledge needed to appreciate the information contained in typical accelerograms. Such understanding will contribute in an important way to the correct use of the basic data and to a clearer picture of the properties of destructive earthquake ground motion. This knowledge will also increase the user's confidence in the accuracy and reliability of the basic data. The object of the report is to explain to the nonspecialist the way in which the information contained in analog traces can be as accurately and completely recovered as is practically feasible. The major emphasis is on the mechanical-optical-photographic recording type of accelerograph which has been standard in the U.S. network for 45 years. Most of the basic ideas and theory will apply with only minor modifications to other types of recordings, such as the waxed paper system used in some standard Japanese accelerographs.

● 3.2-13 Kurata, E., Iai, S. and Tsuchida, H., **Strong-motion earthquake records on the 1978 Izu-Oshima-Kinkai earthquake in port areas,** *Technical Note 317,* Port and Harbour Research Inst., Japan Ministry of Transport, Tokyo, Mar. 1979, 383.

This report presents the strong-motion earthquake records of the 1978 Izu-Oshima-Kinkai earthquake and five major aftershocks recorded in port areas in Japan. The event data of the earthquakes and the maximum component accelerations of all the records are listed. For seven records of the main shock and three records of the largest aftershock, acceleration time histories, integrated velocities and displacements, response spectra, Fourier spectra, and listings of the digitized records are presented. The format of the report and its suggested procedures for data processing are almost identical to those of the preceding annual report.

● 3.2-14 Porter, L. D., Ragsdale, J. T. and McJunkin, R. D., **Processed data from the partial strong-motion records of the Santa Barbara earthquake of 13 August 1978-preliminary results,** *Preliminary Report 23,* Office of Strong-Motion Studies, California Div. of Mines and Geology, Sacramento, 1979, 93.

On Aug. 13, 1978, an earthquake of moderate magnitude (M_L = 5.1, California Inst. of Technology Seismological Lab.) occurred in the ocean 6 km south of Santa Barbara, California. The earthquake, originating at 22:54:52.4 ±0.1 second (GMT), had a focal depth of 12.5 ±3 km and was located (±2 km) at latitude 34.37° N and longitude 119.72° W. Damage to buildings caused by the earthquake was generally slight and consisted mostly of broken glass and plaster.

The Santa Barbara area has a moderate amount of instrumentation, including 27 accelerographs within 90 km of the epicenter. Eleven accelerographs were triggered by the Aug. 13 main event; eight of these instruments belong to the California Div. of Mines and Geology (CDMG), and one each to the Southern California Edison Co., the U.S. Bureau of Reclamation, and the U.S. Geological Survey. The following three CDMG stations in the Santa Barbara area produced records significant enough to require digitization by the state program: (1) the Santa Barbara-Freitas Building, (2) the Santa Barbara-UCSB North Hall Building and (3) Santa Barbara-UCSB Goleta. The subject of this report is the record analysis of approximately the first ten seconds of earthquake-generated motion at these stations. Data presented in this report include uncorrected accelerations, corrected accelerations, velocities and displacements, and response spectra.

● **3.2-15** Hudson, D. E., **Reading and interpreting strong motion accelerograms,** Div. of Engineering and Applied Science, California Inst. of Technology, Pasadena, Oct. 1978, 119.

As of 1978, there were about 5000 strong-motion earthquake accelerographs distributed unevenly throughout the seismic regions of the world. In a typical year, these instruments generate several dozen records of strong earthquake ground motion which are added to the several hundred important records already in existence. Practically all of these accelerographs produce a record as an analog trace of acceleration versus time, either in the form of a photographic trace on film or paper or a scratch on waxed paper. The object of this report is to explain to the nonspecialist how the information contained in these analog traces can be as accurately and completely recovered as possible. The major emphasis is on the mechanical-optical-photographic recording type of accelerograph which has been standard in the U.S. network for about 45 years. Most of the basic ideas and theory apply to other types of recordings, such as the waxed paper system used in some standard Japanese accelerographs.

● **3.2-16** Knudson, C. F. and Perez, V., **Guatemalan strong-motion earthquake records,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 44, 24.

Four accelerographs were installed at temporary aftershock stations in Guatemala at Puerto Santo Tomas, Zacapa, Chichicastenango, and Guatemala City after Feb. 4, 1976, earthquake (magnitude 7.5). Prior to this event, ten records, all less than 0.05 g, had been obtained from the single accelerograph installed at the Observatorio Nacional in Guatemala City. Aftershocks of the 1976 event were recorded at Zacapa, Chichicastenango, and Guatemala City, and produced accelerations of more than 0.10 g. The records have been digitized and standard response spectra, Fourier spectra, and response spectra as a function of time have been computed. These aftershock records form a significant group of Guatemalan accelerograms. Two records from the destructive Feb. 4 earthquake were recovered from seismoscopes installed in the administration building at the university in Guatemala City. One of four accelerographs in the neighboring country of El Salvador recorded the Feb. 4 earthquake, together with fourteen seismoscopes in the metropolitan area of San Salvador.

● **3.2-17** Porter, L. D., Ragsdale, J. T. and McJunkin, R. D., **Processed data from the strong-motion records of the Santa Barbara earthquake of 13 August 1978–final results,** *Special Report 144,* Office of Strong-Motion Studies, California Div. of Mines and Geology, Sacramento, 1979, 3 vols.

This paper presents processed strong-motion data collected from the Aug. 13, 1978, Santa Barbara earthquake by the California Strong Motion Instrumentation Program. The earthquake produced the first significant seismic motions recorded in structures instrumented with central recording accelerographs using multiple channel remote sensors. This report contains the first automatically reconstructed accelerograms. This technique makes possible ultra-precise processing without photo-enlargement and is part of a system for the initiation of data processing using reassembled records.

● **3.2-18** Porcella, R. L. et al., **Compilation of strong-motion records from the August 6, 1979 Coyote Lake earthquake,** *CDMG Preliminary Report 25 and USGS Open-File Report 79-385,* Office of Strong-Motion Studies, California Div. of Mines and Geology, and U.S. Geological Survey, Sacramento and Menlo Park, California, Oct. 1979, 71.

The Aug. 6, 1979, central California earthquake (M_L = 5.7) was located at a depth of about 10 km in the Calaveras fault zone at Coyote Lake near Gilroy, California. Strong-motion accelerographs as far as 114 km from the epicenter were triggered, but only those accelerographs within about 40 km recorded significant accelerations (greater than 0.05 g). A maximum acceleration of 0.42 g was recorded at a station located within the fault zone southeast of the epicenter. This station is part of the Gilroy array which includes six accelerograph stations across the Santa Clara Valley. Records from these and other nearby stations are significant in terms of studies of source parameters, near-field motions, wave propagation, and site effects. Because the instrumented structures from which records were obtained were all at sufficiently long distances from

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

the earthquake, the recorded motions at these stations were small relative to those associated with damage. On the other hand, the structural response records provide important data for the study of a freeway overpass, the torsional response of buildings, and deformation of diaphragms and walls.

● **3.2-19** Vanmarcke, E. H., **Representation of earthquake ground motion: scaled accelerograms and equivalent response spectra,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 14,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1979, 83.

Alternative representations of earthquake ground motion for the purpose of seismic analysis and design are reviewed and critically examined in this report. Emphasis is given to the relation between earthquake time-histories and response spectra. The results of a study on the effects of scaling earthquake records on peak acceleration are presented. Errors attributable to scaling are evaluated in terms of the response for one-degree elastic and elastoplastic systems and the equivalent number of cycles of uniform shear stress. The significance of duration and frequency content is assessed in this context. The pitfalls of the practice of using "standard" design response spectra are pointed out, and a methodology is proposed for developing site-specific design response spectra based on appropriate accelerograms from past earthquakes.

● **3.2-20** Brady, A. G. et al., **Romanian and Greek records, 1972-1977,** *Seismic Engineering Data Report 5, Open-File Report 78-1022,* U.S. Geological Survey, Menlo Park, California, Sept. 1978, 221.

This report contains digitization results and analyses of the Bucharest, Romania, record of Mar. 4, 1977, and several strong-motion earthquake records recorded in Greece from 1972 to 1975.

● **3.2-21** Kurata, E. et al., **Strong-motion earthquake records on the the 1978 Miyagi-ken-oki earthquake in port areas,** *Technical Note 319,* Japan Port and Harbour Research Inst., Tokyo, June 1979, 419.

This report presents the strong-motion earthquake records of the 1978 Miyagi-ken-oki earthquake in port areas in Japan. Event data from the earthquake are listed with the maximum component accelerations of all the records obtained in the network of the Japan Port and Harbour Research Inst. Fourteen records are presented as acceleration time histories, integrated velocities and displacements, response spectra, and Fourier spectra. Digitized records are listed for five records. This report has similar format and procedures for data processing as the preceding annual report.

● **3.2-22** Kausel, E. and Ushijima, R., **Baseline correction of earthquake records in the frequency domain,** *Research Report R79-34,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, July 1979, 77.

This report examines various integration schemes for discrete functions in the frequency domain and develops procedures to perform a parabolic baseline correction to earthquake records in this domain. Only for acceleration records having zero mean value over the interval of definition does the simplest integration scheme analyzed (the "pseudo-continuous method") coincide with the well-known "integration" procedure of dividing the Fourier transform of the record by $\Omega \sqrt{-1}$. Records with no-zero mean, on the other hand, require additional terms to achieve consistency with time-domain procedures such as the trapezoidal rule. The formulas developed are then applied in the last section of the report to the Golden Gate earthquake of Mar. 22, 1957, and compared with each other.

● **3.2-23** Naumovski, N. et al., **Preliminary analysis of strong motion records obtained at Ulcinj, Bar and Petrovac from April 15 1979 Monte Negro-Yugoslavia earthquake** (in English and Serbo-Croatian), *64,* Inst. of Earthquake Engineering and Engineering Seismology, Univ. "Kiril and Metodij," Skopje, Yugoslavia, Apr. 1979, 78.

● **3.2-24** Shiono, K., **Wave type identification of a downhole array record** (in Japanese), *Transactions of the Architectural Institute of Japan, 282,* Aug. 1979, 65-70.

A strong-motion record obtained by means of a downhole array is analyzed with special reference to wave types and the significance of downhole array recordings for wave identification. It is clarified by the analysis that vertical and horizontal motions are composed mainly of P- and S-waves, respectively. The following general observations can be made as a result of the analysis. (1) A direct comparison of amplitude-depth relationships to theoretical mode shapes for various wave types is an effective means for wave identification. (2) Rayleigh waves can be identified from other wave types by means of an analysis of the amplitude-depth relationships. (3) In some cases, because of the similarity of mode shapes, the amplitude-depth relationships are insufficient for distinguishing between S-waves and Love waves. Additional information from the frequency-time characteristics is useful in this case. (4) The apparent horizontal velocity which cannot be analyzed by means of downhole array recordings may be the most effective means for distinguishing between body and surface waves. This suggests the significance of horizontal array recordings.

● **3.2-25** Midorikawa, S. and Kobayashi, H., **On estimation of strong earthquake motions with regard to fault rupture** (in Japanese, with English summary), *Transactions* *of the Architectural Institute of Japan,* 282, Aug. 1979, 71–81.

● 3.2-26 Brady, A. G., **Strong motion data management,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 253–263. (For a full bibliographic citation, see Abstract No. 1.2–16.)

The National Science Foundation supports a program of strong-motion instrumentation and data management conducted by the U.S. Geological Survey with a primary focus on the management of strong-motion data. The objective of the program is to catalog, process, and analyze recovered data and to disseminate results and information about these records and the program. The contents of a data base containing information on the stations, the records recovered since the 1930s, and the events giving the records are available by remote terminal. Digital data are available on tape, and plotted results are available in reports. A typical example of the analysis procedures is illustrated with records from the Santa Barbara earthquake of Aug. 13, 1978.

● 3.2-27 Bicanic, N., **Structure dependent short duration combisweep accelerogram,** *International Conference on Computer Applications in Civil Engineering, October 23–25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-67–72.

A structure-dependent, short-duration combisweep accelerogram, a modification of the Johnson/Epstein sinesweep accelerogram, is presented. The free parameters for this frequency- and amplitude-modulated sinusoidal signal are obtained as the solution to the optimization problem, where the distance between the response spectrum and the target response spectrum is minimized only for the discrete points which coincide with the natural frequencies of the structure. To demonstrate the procedure, a Koyna Dam combisweep accelerogram, compatible with the response spectrum of the transversal component of the Koyna Dam accelerogram, is developed. Some limited experience with comparative linear and nonlinear analyses is also presented.

● 3.2-28 Kanamori, H., **A semi-empirical approach to prediction of long-period ground motions from great earthquakes,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 1645–1670.

Predictability of long-period (1 sec or longer) ground motions generated by long strike-slip earthquakes, such as the 1906 San Francisco and the 1857 Fort Tejon, California, earthquakes, is investigated. Most large earthquakes are complex multiple events at this period range, and the resulting ground motion may be synthesized by convolving the ground motions of the individual event with the source function that describes the space-time history of the multiple shock sequence. Since it is not possible to predict deterministically the complexity of the rupture propagation, a semi-empirical approach was taken. For the ground motion from the individual events, the displacement records observed for the 1968 Borrego Mountain, California, earthquake were used after correcting for the distance and the radiation pattern. These records which were used as an empirical Green's function for the individual events were superposed, with some randomness, to produce ground motions resulting from a large earthquake. The models were constrained by gross seismological data at three periods. At 1 sec, they are constrained by the observed upper bound of the local magnitude (M_L = 7 1/4), and, at about 10 sec, by the upper bound of the seismic moment of the individual event of multiple shocks (5 x 10^{26} dyne-cm). At very long periods, the models have the correct total seismic moment. The results obtained for a model of the 1857 earthquake indicate that: (1) the velocity response spectra of ground motions in the near-field are nearly flat at about 50 cm/sec over the period range from 1 to 10 sec under normal conditions; (2) under certain circumstances, they can be as large as 150 cm/sec; (3) the maximum duration of the ground motion is 6 min. These results are considered reasonable because they satisfy all the seismological constraints currently available over a wide period range.

3.2-29 Medvedev, S. V. and Fedyakova, S. N., **Evaluation of seismic response in the area of Petropavlovsk-Kamchatsk** (Otsenka spektrov seismicheskikh kolebanii na territorii g. Petropavlovska-Kamchatskogo, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 28–39.

Spectra of earthquake records (energy class **K** from 11 to 15) are analyzed. The records, obtained at locations in the Petropavlovsk-Kamchatsk area featuring a variety of soil conditions, shed light on the ways that geological conditions, earthquake energy, and epicentral azimuth affect the spectrum of vibrations.

3.2-30 Bogdanov, V. I., Graizer, V. M. and Shebalin, N. V., **Determination of true motion and of residual soil displacement from seismograms of aftershocks of strong-motion earthquakes** (Opredelenie istinnogo dvizheniya i ostatochnogo smeshcheniya pochvy po seismogrammam povtornykh tolchkov sil'nykh zemletryasenii, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 98–107.

An algorithm for determining residual soil displacement from galvanometrically recorded seismograms is presented. Results of application of the method to records of aftershocks of the May 14, 1970, Dagestan earthquake and the Apr. 8 and May 17, 1976, Gazlii earthquakes in the U.S.S.R. are reported. The scope of problems to which the

● *See* ***Preface****, page v, for availability of publications marked with dot.*

algorithm can be applied with success (correction of instrument errors, soil slump amplitude, and deformation of buildings) is examined.

● 3.2-31 Aspinall, W. P., **The 14 August 1977 earthquake near Trinidad,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 44-70. (For a full bibliographic citation, see Abstract No. 1.2-21.)

A magnitude 4.9 m_b (body wave) earthquake occurred at 0423 GMT, Aug. 14, 1977, at 10.98°N 62.37°W and with a focal depth of 112 km. It was felt in Trinidad with intensities up to Mercalli VI, with intensity IV in Grenada, and with intensity III-IV in Tobago. Four strong-motion accelerographs in northwest Trinidad were triggered during the event producing three records of ground motions and a record from the roof level of a 9-story steel-frame building. The peak horizontal ground acceleration was 41 cm/sec^2 at St. Clair, and on the roof of the TEXTEL building the maximum was 64 cm/sec^2. Analyses of the accelerograph records from the 9-story building indicate the primary fundamental modes of the response of the building and these can be compared with the values calculated by model dynamic response programs. The intensity of shaking and the amplitudes of recorded accelerograms seem anomalously high for an earthquake of magnitude 4.9 m_b at a hypocentral range of 150 km; this raises questions about the true magnitude of the event and the relative intensities observed and, if these are both reliable, whether a much larger earthquake in the same hypocentral source volume would produce excessive intensities in Trinidad.

● 3.2-32 **Uncorrected digitized acceleration records of the Tangshan earthquake, July 28, 1976** (in Chinese), Inst. of Engineering Mechanics, Academia Sinica [Beijing], 1978, 2 vols., 380.

The chapter titles in this 2 vol. publication, written entirely in Chinese, are: (1) Earthquake catalog, (2) Strong motion recording stations, (3) Strong motion recording station in Tangshan area, (4) Catalog of acceleration records, (5) Uncorrected digitized acceleration records, and (6) Time history of acceleration records.

3.2-33 Kuz'mina, N. V., **Earthquakes from the Gazlii district, according to observations at the Dushanbe engineering seismometric station** (Zemletryaseniya iz raiona Gazlii po nablyudeniyam na inzhenerno-seismometricheskoi stantsii g. Dushanbe, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 50-59.

Vibrations occurring during three earthquakes are analyzed for a tower-type eight-story monolithic dwelling constructed of agglomerate-foam concrete. Amplitudes of the building's vibrations are shown to increase by one order of magnitude as the earthquake magnitude ranges from 5.5 to 7. The periods of the vibrations varied negligibly. Amplitude spectra of displacements and accelerations in the May 17, 1976, earthquake are reported. The spectra of the upper floor slabs of the building display a conspicuous peak at the frequency of the natural vibration of the building. The peak amplitude in the attic spectrum was an entire order of magnitude greater than the peak amplitude in the basement spectrum.

● 3.2-34 **Accelerograms from the Friuli, Italy, earthquake of May 6, 1976 and aftershocks. Part 4: 178 through 243, uncorrected,** *Strong Motion Earthquake Accelerograms: Digitized and Plotted Data, Vol. I, Part 4,* Commissione CNEN-ENEL per lo Studio dei Problemi Sismici Connessi con la Realizzazione di Impianti Nucleari, Rome, Italy, July 1978, 432.

This is the fourth part of the Friuli uncorrected data relating to the set of digitizable accelerograms recorded by the CNEN-ENEL stationary and mobile accelerographic stations up to Dec. 31, 1976.

● 3.2-35 **Accelerograms from the Friuli, Italy, earthquake of May 6, 1976 and aftershocks. Part 5: 244 through 272, uncorrected,** *Strong Motion Earthquake Accelerograms: Digitized and Plotted Data, Vol. I, Part 5,* Commissione CNEN-ENEL per lo Studio dei Problemi Sismici Connessi con la Relizzazione di Impianti Nucleari, Rome, Italy, July 1979, 156.

With this volume, the series dedicated to the uncorrected data from the Friuli earthquake and aftershocks is completed. Synoptic tables are included to summarize the data collected in all five volumes in the series and to offer a compact description of the characteristics of the recorded accelerograms.

● 3.2-36 **Strong-motion earthquake accelerograms. digitized and plotted data. Volume II–uncorrected data. Part A–accelerograms IIA01 - IIA09,** *57,* Inst. of Earthquake Engineering and Engineering Seismology, Univ. "Kiril and Metodij," Skopje, Yugoslavia, 1977, 64.

This publication contains uncorrected data for nine strong-motion records recorded in the territory of Yugoslavia in 1973 and 1974.

● 3.2-37 Borg, S. F., **Accelerogram, intensity, damage–a new correlation for use in earthquake engineering design,** *Technical Report ME/CE-791,* Dept. of Mechanical Engineering/Civil Engineering, Stevens Inst. of Technology, Hoboken, New Jersey, Dec. 1979, 28.

A most important and useful record of an earthquake is the accelerogram which is a printout of acceleration in a given direction as a function of time at a given locality. This paper presents a new unifying concept or invariant for this fundamental data, based upon a rigorous mathematical

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

and physical argument. Various properties and uses of the invariant are developed. In addition, a postulated damage criterion which is founded on this invariant will be described. The paper concludes with suggestions for future research.

3.2-38 Bouchon, M., **Predictability of ground displacement and velocity near an earthquake fault: an example: the Parkfield earthquake of 1966,** *Journal of Geophysical Research,* **84,** *B11,* Paper 9B0882, Oct. 10, 1979, 6149–6156.

Using the discrete wave number representation method, the authors model the Parkfield earthquake of 1966 as a Haskell-type dislocation source embedded in a layered medium. It is shown that the displacement and velocity recorded near the source (station 2 of the Cholame-Shandon array) can be fully accounted for by the propagation of the rupture on the branch of the fault closest to the station. The slip and slip velocity inferred are about 40 cm and 130 cm/s, respectively. The ground motion at the accelerograph site and in the region close to the source was very strongly amplified by the sedimentary layer. The rupture, after being initiated at depth, stayed buried well under the sediments on the main segment of the fault. The dislocation then jumped across Cholame Valley and became quite shallow. On this southeast branch of the fault, the rupture most likely penetrated the sediments. The results obtained constitute an encouraging step toward predicting the strong ground motion at a given site for a potential earthquake fault.

3.2-39 Katayama, T., Iwasaki, T. and Saeki, M., **Statistical analysis of earthquake acceleration response spectra,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 311–313. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 275,* July 1978, 29–40.)

A statistical analysis was conducted for 277 acceleration response spectral amplitudes at each of the 18 natural periods of a SDOF system in terms of earthquake magnitude, epicentral distance, and recording-site ground conditions. The accelerograms used for analysis were the horizontal components of 67 earthquakes recorded at various places in Japan during 1956 and 1974. Magnitude, distance, and site conditions were divided into several discrete categories as shown in tabular form and a prediction formula was assumed. The values of the weighting factors were determined so that the predicted spectral amplitudes agreed well with the measured spectral amplitudes. The results obtained for each of the 18 natural periods are summarized.

3.3 Artificial and Simulated Earthquake Records

● 3.3-1 Kubo, T. and Suzuki, N., **Simulation of earthquake ground motion and its application to response analysis** (in Japanese), *Transactions of the Architectural Institute of Japan, 275,* Jan. 1979, 33–43.

Two types of earthquake motion models are introduced. Characteristics of synthetic earthquake motions simulating recorded motions are evaluated and the response properties of the recorded and the synthetic motions are correlated. Under certain conditions, a time function uniquely corresponds to its Fourier transform, i.e., to its Fourier phase and Fourier amplitude spectra. The Type I model is used to determine the Fourier phase spectrum by means of an analysis of a recorded motion and to assign uniformly distributed random numbers to the Fourier amplitudes. The Type II model is used to determine the Fourier amplitude spectrum by applying random angles to the Fourier phase spectrum.

Simulating the motions of the 1940 El Centro and the 1968 Hachinohe Harbour, Tokachi-oki earthquakes, the authors produced 20 samples of synthetic motions by means of the Type I and Type II models, respectively. Such characteristics of synthetic motions as cumulative energy distributions and elastic and inelastic response spectra are evaluated and the results are compared statistically with those results obtained for the recorded motions. A summary of the properties of the synthetic motions follows: (1) Cumulative energy distributions for the Type I motions have similar values with a small deviation around the mean when taken across 20 samples of synthetic motions. (2) While the mean of the maximum elastic responses for the Type I motions is a uniform value which is dissimilar to the response for the recorded motion, the mean of the maximum responses for the Type II motions is in good agreement with the response for the recorded motion over the entire range of periods. (3) On an average, 17 cases out of 20 of the maximum elastic responses for the Type II motions fall not greater than the mean plus one standard deviation. (4) For the inelastic response, the maximum response of the recorded motion lies in the range between the mean minus one standard deviation and the mean plus one standard deviation when taken across the 20 responses of the Type II motions.

● 3.3-2 Kubo, T. and Penzien, J., **Simulation of three-dimensional strong ground motions along principal axes, San Fernando earthquake,** *Earthquake Engineering & Structural Dynamics,* **7,** *3,* May-June 1979, 279–294.

Power spectral density which describes frequency content is considered one of the most significant properties to be taken into account when generating ground motions

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

by the use of stochastic processes. Using a smoothed and normalized Fourier amplitude spectrum, frequency content for components of motion along a set of principal axes is estimated. Fourier amplitude spectra obtained by this moving window technique are presented; the spectra show the time dependency of frequency content for motions produced by the San Fernando earthquake of Feb. 9, 1971. A mathematical model to simulate ground motion processes is proposed for which both the intensity and frequency content are nonstationary. Using this mathematical model with parameter characteristics along principal axes similar to those of the motions recorded during the San Fernando earthquake, three-dimensional ground motions are generated synthetically. The properties of the simulated motions show general characteristics similar to those observed in real accelerograms. The suggested model is considered adequate for engineering purposes.

● 3.3-3 Fujita, T. and Shibata, H., **On a model of earthquake ground motions for response analysis and some example of analysis through experiment,** *Engineering Design for Earthquake Environments,* Paper No. C184/78, 139-148. (For a full bibliographic citation, see Abstract No. 1.2-2.)

This paper describes an earthquake ground motion model for the response analysis of such industrial facilities as nuclear power plants, petrochemical plants, tank yards, and other plants having critical influences on environmental safety. Since 1972, the authors have observed the responses of a model plant, including its piping systems, towers, and oil storage facilities. More than 100 records have been obtained of responses of such structures to ground motions from 2 to 30 gal. The distribution of amplification and response factors appears to be normal, even though several earthquakes showed highly abnormal values up to as much as three times the mean. The recorded earthquake ground motions (including the abnormal cases) are represented artificially by combining random and sinusoidal waves. Vibration experiments were conducted on a rectangular, fluid-filled vessel with leg supports; sloshing of the fluid was observed during the experiments. Comparisons are made of the experimental results and the results calculated using the artificial ground motions.

● 3.3-4 Kubo, T. and Penzien, J., **Analysis of three-dimensional strong ground motions along principal axes, San Fernando earthquake,** *Earthquake Engineering & Structural Dynamics, 7, 3,* May-June 1979, 265-278.

An orthogonal set of principal axes is defined for earthquake ground motions. These principal axes are obtained such that the corresponding variances of motion have maximum, minimum, and intermediate values and the covariances equal zero. This indicates that the corresponding components of motion along the principal axes are uncorrelated with respect to each other. Since real earthquake accelerograms are assumed to be reasonably well represented by Gaussian random processes, the three components of motion along the principal axes are statistically independent of each other. Using these principal axes and applying the moving window technique to the ground accelerograms recorded during the San Fernando earthquake of Feb. 9, 1971, time-dependent characteristics of three-dimensional ground motions along principal axes are determined. Results of the analysis indicate significant correlation between directions of principal axes and directions from the recording stations to the fault slip zone. It is concluded that three components of ground motion can be generated stochastically with statistical independence maintained, provided the components are assumed to be directed along principal axes.

● 3.3-5 Herrmann, R. B. et al., **Strong motion studies in the central United States,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 279-285. (For a full bibliographic citation, see Abstract No. 1.2-16.)

This paper describes a method for estimating realistic strong ground motions for earthquakes in the central United States. The method involves the computation of complete synthetic time histories from point dislocation sources buried in a plane layered medium at distances of 10 to 500 km. While this development is important on seismological, numerical, and esthetic grounds, efforts are being made to test the usefulness of the method for engineering applications. One criticism of the method is that, even though a reasonably complex earth model can now be considered, the earth model can never be as complex as the real earth. On the other hand, the synthetic time histories can be used to obtain a better theoretical understanding of how peak ground motion parameters, such as maximum ground velocity or acceleration, vary with the earthquake source frequency content, distance, magnitude, or even the earth model. It is hoped that this practical effort will lead to an understanding of how much of the scatter in the present strong-motion estimators is caused by the earth and how much is a result of the underparameterization of the earthquake and wave transmission processes.

● 3.3-6 Watabe, M. and Tohdo, M., **Analyses on various parameters for the simulation of three-dimensional earthquake ground motions,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/1, 11. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In the seismic design of such complex structures as nuclear power plants, it is important to consider the simultaneous response effects caused by three-dimensional earthquake excitations. Because of the lack of recorded strong-motion accelerograms, it is necessary to generate

● *See* ***Preface****, page v, for availability of publications marked with dot.*

simulated earthquake ground motions. This paper reviews various earthquake motion parameters and then presents the results of analyses of parameters necessary for the simulation of three-dimensional earthquake ground motions. Stochastic methods are extensively used to analyze several hundred strong-motion accelerograms obtained in Japan and the United States. Stochastic correlations of such earthquake ground motion maxima as maximum acceleration, velocity, displacement and spectral intensity are introduced. Equations for correlating such maxima with focal distance and earthquake magnitude are also introduced. The significance of effective peak acceleration for practical engineering purposes is mentioned. A new deterministic intensity function concept derived from mathematical models is presented. With use of this concept, deterministic intensity functions for horizontal components as well as vertical are obtained. The relation between duration time and magnitude is also introduced.

Spectral characteristics of earthquake ground motions are also considered in the paper. The velocity response spectrum on free-field bedrock is assumed to be a function of the magnitude of an earthquake and its focal distance in addition to being a function of its period and damping ratio. Using accelerograms obtained on free-field bedrock in Japan, the response spectrum for a horizontal component is obtained and the spectrum for the vertical component is discussed. The possibility of using the concept of principal axes for the simulation of three-dimensional earthquake ground motions is discussed. It is concluded that generated uncoupled three-component earthquake ground motions along principal axes can be transformed into any orthogonal components having arbitrary covariances.

● 3.3-7 Watabe, M., Chiba, O. and Tohdo, M., **Generation of simulated three-dimensional earthquake ground motions,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/2, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes the simulation of three-dimensional earthquake ground motions by means of the concept of principal axes introduced in the paper. In generating the earthquake ground motions, it is important to establish the relation between the maximum response values and the factors of the input process. A simple approach for estimating the maximum response of a structure subjected to nonstationary random excitations is proposed as a product of the square root of the mean square of response values and the magnification coefficient, with a constant expressing the nonstationarity of the input process. This analytical method is applied to simulate nonstationary earthquake ground motions having an appropriate smooth design response spectra and to evaluate the maximum response of a multistoried structure and its floor response spectrum. The principal axes used in the simulation of earthquake ground motions have corresponding variances of motions with maximum, minimum, and intermediate values and their covariances equal to zero. Using this concept, three-dimensional earthquake ground motions can be simulated in a completely synthetic way as the product of a stationary random process and a deterministic intensity function. In the stochastic modeling of earthquake ground motions, phase angles are generally considered as random values with a uniform distribution. However, phase spectra and amplitude spectra are important in the time domain of each sample. According to the basic analyses, it is found that phase angles play an important role in determining the characteristics of time history and the covariances. These results are applied to simulate three-dimensional earthquake ground motions appropriate to the given design response spectra.

● 3.3-8 Oliver, R. M. and Pister, K. S., **A class of models for identification and simulation of earthquake ground motions,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/10, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper outlines the use of discrete, autoregressive/moving-average (ARMA) models for identification and estimation of parameters in models derived from analysis of uniformly digitized earthquake ground motion acceleration data. Such models are of equal generality as compared to continuous-time models and have a number of significant advantages for purposes of digital analysis and simulation. The structure of ARMA models is briefly described, their relation to continuous models noted, and results of their application to a number of recorded accelerograms summarized.

● 3.3-9 Wong, H. L. and Trifunac, M. D., **Generation of artificial strong motion accelerograms,** *Earthquake Engineering & Structural Dynamics,* 7, 6, Nov.-Dec. 1979, 509-527.

A method for generating synthetic strong-motion accelerograms for use in engineering design is presented. This method utilizes the model proposed by Trifunac in conjunction with the recent empirical scaling functions for characterization of amplitudes and duration of strong shaking in terms of (i) earthquake magnitude and epicentral distance or (ii) modified Mercalli intensity at the recording station. The method also enables one to consider the desired levels of confidence that the synthetic motion will not be exceeded, the direction of ground motion (horizontal or vertical), and the dispersive properties of the geologic environment beneath and surrounding the station. The principal features of this approach are that the resulting accelerograms have nonstationary frequency and amplitude characteristics which are in full agreement with known principles of wave propagation through a stratified

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

medium, and that the Fourier amplitudes and the frequency-dependent duration are scaled in accordance with known trends as in recorded accelerograms.

● 3.3-10 Jurkevics, A. and Ulrych, T. J., **Autoregressive parameters for a suite of strong-motion accelerograms,** *Bulletin of the Seismological Society of America,* 69, 6, Dec. 1979, 2025–2036.

The time-adaptive technique of Jurkevics and Ulrych has been used to analyze a suite of rock-site accelerograms recorded during two M_L = 6.4 earthquakes in California. One of the parameters which models the earthquake, the innovation variance, has been found to vary with epicentral distance. The shaking duration exhibits a linear variation with log (D) after a finite distance away from the fault. The above results allow the construction of artificial accelerograms for arbitrary epicentral distances for M_L = 6.4 earthquakes in California.

● 3.3-11 Chang, M. K. et al., **ARMA models for earthquake ground motions,** *UCB/EERC-79/19,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 97. (NTIS Accession No. PB 301 166)

This report contains an analysis of four major California earthquake records using a class of discrete linear time-domain processes commonly referred to as ARMA (autoregressive/moving-average) models. In the report, the order of the appropriate ARMA models has been identified, parameters estimated, and the residuals generated by these models tested. Shown are the connections, similarities, and differences between the traditional continuous models with parameter estimates based on spectral analyses and the discrete models with parameters estimated by various maximum likelihood techniques applied to digitized acceleration data in the time domain. The methodology proposed is suitable for simulating earthquake ground motions in the time domain and appears to be easily adapted to serve as inputs for nonlinear discrete time models of structural motions.

3.4 Seismic Zoning

● 3.4-1 Basham, P. W. and Weichert, D. H., **Seismic risk mapping in Canada,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 23–48.

This paper describes research directed toward a number of aspects of seismic risk mapping for purposes of recommending changes in the next version of the seismic zoning map of Canada. A modified analysis technique, which integrates risk (e.g., of peak acceleration exceedence) at a site from earthquakes occurring uniformly with specified rates in zones of earthquake occurrence, is applied to a number of sites in Canada. In eastern Canada, the available geologic and tectonic data provide no reliable guidelines to define boundaries for the zones of earthquake occurrence. The zones, therefore, are based principally on the distribution of historical seismicity. In some regions of the Pacific coast, the known tectonic features and major fault systems provide more reliable constraints on the adopted seismicity model. Results for risk levels near 10^{-2} per annum are not strongly influenced by reasonable variations in the model parameters. At lower risk levels for sites near the most active zones, the results can be highly dependent on the assumed zonal maximum magnitude. Peak accelerations at risk levels near 10^{-2} per annum are generally consistent with those displayed on the 1970 seismic zoning map, but there are differences in detail caused mainly by the different analysis technique.

● 3.4-2 Bentley, R. J. and Zen, M. T., **The seismic zoning of Indonesia for normal building construction,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 760–763.

This paper outlines the method of approach adopted in a comprehensive review by Indonesian and New Zealand scientists and engineers of seismic risk in Indonesia and the preparation of a seismic zoning map for normal building construction.

● 3.4-3 Suggate, R. P., **Seismotectonics and earthquake risk macrozoning in New Zealand,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 21–31.

Seismological and geological studies must be combined into a seismotectonic approach before better macrozones of earthquake risk can be designated. Since the publishing of such zones as New Zealand Standard NZS 1900, 1965, pertinent studies have been made on the frequency of earthquake occurrence, the periodicity of faulting in different tectonic regions, and the present geodetic strain rates. Integration of these and previous studies may result in agreed seismotectonic zoning, but the conversion to risk zones requires different types of decisions dependent upon the assessment of the risks themselves and of the significance of differences of risk in relation to zone boundaries.

● 3.4-4 Mihailov, V., **Sensitivity analysis of uncertainty in seismic sources modeling on seismic hazard mapped parameters,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 783–792.

● *See **Preface,** page v, for availability of publications marked with dot.*

Current methods of seismic hazard analysis take into account seismological and geological information in calculating probabilistic predictions of future earthquakes. However, limited knowledge of the causes of earthquakes and the shortness of recorded seismic history lead to statistical uncertainties concerning seismic parameters. Statistical uncertainties in defining some parameters of seismicity, especially the type, size, and geometrical characteristics of the seismic sources, can have a great effect on the calculation of the seismic hazard. The effect is assessed by deriving the probability distribution of the important seismic parameters. Seismic model formulation requires available seismic source parameters to calculate the probabilistic hazard. Because these parameters in practice are determined in varying ways, it is important to judge the sensitivity of mapped values to these parameters. The uncertainties of the seismic sources, activity rates, and maximum possible magnitude are described using earthquake data from Macedonia for a period of 75 yr. The influence of these uncertainties on the seismic hazard is illustrated.

● **3.4-5** Mortgat, C. P. and Shah, H. C., **A Bayesian model for seismic hazard mapping,** *Bulletin of the Seismological Society of America,* **69,** *4,* Aug. 1979, 1237–1251.

The paper presents a Bayesian model for seismic hazard mapping. The main features of the model follow. Faults are modeled by deterministically located dipping planes; several planes (trapezoids) can be combined within a source to satisfy geometric constraints. Area sources are modeled by horizontal trapezoids, and line sources at constant depth are modeled by one or a series of straight line segments. The tectonic model considers a rupture area (plane sources) or a rupture length (line sources) associated with each magnitude event. The seismicity is modeled in two steps. On each source, events, which occur independently of magnitude, are assumed to follow a Poisson model. Distribution of magnitudes is obtained using a Bernoulli process. In modeling the seismicity and tectonics, insufficient data is supplemented by the incorporation of subjective information which is derived using Bayesian statistical concepts. A lognormal distribution is used to take into account the uncertainty in attenuation. The significant distance for attenuation purposes is chosen as the closest distance from the rupture area (length) to the site. Finally, to simplify the mapping procedure, this model makes it possible for a number of mapping parameters (governed by core limitations) to be obtained in a single run at the nodes of an entire grid.

● **3.4-6** Suggate, R. P., **Seismotectonics and earthquake risk macrozoning in New Zealand,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, 3–6.

Seismological and geological studies must be combined into a seismotectonic approach before better macrozones of earthquake risk can be designated. Since such zones were published in 1965 as New Zealand Standard NZS 1900, pertinent studies have been made on the frequency of earthquake occurrence, the periodicity of faulting in different tectonic regions, and the present geodetic strain rates. Integration of these and previous studies may result in acceptable seismotectonic zoning, but the conversion to risk zones requires different types of decisions dependent on the assessment of the risks themselves and of the significance of differences in risk in relation to zone boundaries.

● 3.4-7 Kiremidjian, A. S., Shah, H. C. and Zsutty, T. C., **Seismic hazard mapping for Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 46, 8.

This paper summarizes the results of a seismic hazard mapping study of Guatemala. Iso-acceleration and iso-duration maps for return periods of 50 years, 100 years, 500 years, and 1000 years are developed. Two currently available models for hazard mapping are used: the Poisson model and the Bayesian model. The paper discusses the advantages and shortcomings of these two models. A seismic zoning map, based on the iso-acceleration maps, is presented for use in developing the seismic design provisions for Guatemala.

● 3.4-8 Espinosa, A. F., Asturias, J. and Quesada, A., **Applying the lessons learned in the 1976 Guatemalan earthquake to earthquake-hazard-zoning problems in Guatemala** (Intensidad, reduccion de peligro y problemas de la zona sismica en Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 47, 91.

The effects of the magnitude (M_S) 7.5, Feb. 4, 1976, earthquake have been documented and studied in more detail than the effects of any other earthquake in Guatemala. The results of the studies provide information essential for the earthquake hazard zoning of Guatemala. One of the most important lessons learned from this earthquake is that serious inconsistencies exist between vibrational and nonvibrational effects, as noted in the MMI scale. For example, phenomena such as bent rails, destroyed bridges, ground cracking, landsliding, liquefaction, and waves seen on the ground surfaces, which indicate intensities of VIII to XII according to the MMI scale, occurred in areas where building damage indicated intensities of V to IX. The inconsistency in the MMI scale must be recognized in earthquake hazard zoning; otherwise, the zoning may be misleading.

● *See **Preface,** page v, for availability of publications marked with dot.*

Other factors must also be considered in the earthquake hazard zoning of Guatemala: (1) modern earthquake-resistant structures and lifelines in Guatemala City can be damaged in a severe earthquake; (2) poor soil conditions always contribute significantly to the damage distribution; (3) the seismic energy near the ruptured fault can be highly asymmetrical; (4) physical effects, such as slumping, landsliding, liquefaction, surface fracture, and differential earth settlement, can occur at great distances from the epicenter; and (5) the spatial distribution of damage to adobe construction can vary widely as a consequence of the direction and complexity of the fault rupture. Since the 1976 earthquake, all of the MMI data have been carefully reevaluated to remove all inconsistencies between vibrational and nonvibrational effects. A map that shows the intensity distribution, the secondary faulting, and landslides has been prepared for Guatemala City. This map will be useful for earthquake hazard zoning. Another map showing the intensity distribution, faulting, landslides, and liquefaction effects has been prepared for the Republic of Guatemala.

3.4-9 Bune, V. I., Leonov, N. N. and Katrikh, I. R., **Dependence of areas of destructive shocks on earthquake magnitude in Europe and Central Asia** (Zavisimost' ploshchadei razrushitel'nykh sotryasenii ot magnitudy zemletryasenii v Evrope i Srednei Azii, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 167–170.

The relationship between areas affected by destructive earthquakes and magnitude (5.3 to 8.7) is discussed in reference to 27 earthquakes recorded in Central Asia and 51 earthquakes recorded in Europe. The paper compares parameters of isoseismal models useful in seismic zoning, and draws on results of estimated mean radii of isoseismal lines (concentric ellipses).

3.4-10 Yudakhin, F. N. and Marinchenko, G. G., **Magnetic fields and seismicity of the Tien Shan** (Magnitnye polya i seismichnost' Tyan'-Shanya, in Russian), *Geologo-Geofizicheskie Osobennosti i Seismichnost' Territorii Kirgizii,* Ilim, Frunze, U.S.S.R., 1978, 13–29.

A ΔTa map of the magnetic field of the territory of Kirghizia and adjacent regions of Uzbekistan and Kazakhstan is compiled, with reduction to a single absolute level. Zonation of the Tien Shan territory is based on features of the magnetic field. Anomalous regions and zones separated by deep faults are discerned. A relationship between magnetic field patterns and seismicity is established. Regions of high seismic activity correspond to sharply varying high-gradient magnetic fields, while quiescent and weak magnetic fields are correlated with low-seismicity regions.

3.4-11 Ershov, I. A. and Popova, E. V., **The effect of saturation of soils on seismic response** (O vliyanii obvodnennosti gruntov na intensivnost' seismicheskogo vozdeistviya, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 117–139.

Effects of saturation of different soils on intensity of seismic response are discussed in relation to seismic microzonation. Soil classification is compared with seismic response patterns, and as a possible guide in forecasting the seismic response of saturated soils. Experimental data obtained at the Inst. of Earth Physics of the U.S.S.R. Academy of Sciences and elsewhere in studies of seismic response are reported.

3.4-12 Shvartsman, Yu. G. and Palamarchuk, V. K., **A note on studies of relative isostatic anomalies in seismic zoning of the territory of the Kirghiz SSR** (K voprosu ob izuchenii otnositel'nykh izostaticheskikh anomalii pri seismicheskom raionirovanii territorii Kirgizskoi SSR, in Russian), *Geologo-Geofizicheskie Osobennosti i Seismichnost' Territorii Kirgizii,* Ilim, Frunze, U.S.S.R., 1978, 38–46.

Relative isostatic anomalies in the territory of Kirghizia are found as a result of the transformation of data from regional gravitational surveys, making use of observations taken at a single height above sea level. An attempt is made to relate the weak intensity of the anomalies to the presumed Mesozoic dating of their origin. Intensities of the gradients of the isostatic anomalies were used in discerning 12 seismic zones in the territory of the republic; these were divisible into 4 classes on the basis of degree of seismic risk.

● **3.4-13** Rosenhauer, W. and Ahorner, L., **Seismic risk map for the western part of central Europe,** *Atomwirtschaft-atomtechnik,* 23, 6, June 1978, 285–288.

3.4-14 Polyakov, S. V. and Zharov, A. M., **Requirements for a seismic zoning map of the nation, as an aid in solving construction planning problems** (Trebovaniya k karte seismicheskogo raionirovaniya strany v svyazi s zadachami proektirovaniya sooruzhenii, in Russian), *Seismotektonika yuzhnykh raionov SSSR,* Nauka, Moscow, 1978, 115–120.

Attention is directed to causes of computational errors incurred in compiling past seismic zoning maps and the 1975 map for the U.S.S.R.; these factors lead to numerous and serious errors in forecasting the intensity of expected earthquakes. It is stressed that builders are not interested in average indices of possible recurrence of strong-motion earthquakes over thousand-year periods, and that what is required are forecasts for the immediate decades ahead. Typical accelerograms have to be produced for construction sites, depending on the location of local seismogenic zones and the parameters of possible earthquakes occurring

● *See **Preface**, page v, for availability of publications marked with dot.*

in the zones. The crucial role that seismogenic zones associated with faults can play in the solution of earthquake-resistant construction problems is emphasized.

3.5 Influence of Geology and Soils on Ground Motion

● 3.5-1 Kitagawa, Y. and Ozaki, M., **Study on regional characteristics of earthquake motions in Japan (Part 2: earthquake danger based on seismic activity and characteristics of soil-layers in period range of 2 to 6 sec.)** (in Japanese), *Transactions of the Architectural Institute of Japan, 277,* Mar. 1979, 33-43.

This paper deals with the regional distribution over a fairly large area of the deep ground characteristics of soil layers in the long-period range of $6.0 \geq T \geq 2.0$ sec. Seismic data from strong-motion seismographs operated by the Japan Meteorological Agency were used. The distributions of the magnification of soil layers are shown. Areas where the magnification factor is high are generally as follows: (1) the Japan Sea coast from the Tohoku district to the Hokkaido district, (2) the southern area of the Kwanto district to the Kinki district, (3) the southwestern area of the Shikoku district to the Kyushu district. The above tendency of the regional distribution varies in detail according to the period components of earthquake motions. The relations between the magnitude (M) and the predominant period (T) of earthquake motion ($\log T = aM + b$) and the relations between the maximum amplitude of the vertical and the horizontal components (R_m) are examined. The regional distributions of coefficients a, b and R_m are indicated. From these figures, it is pointed out that the coefficients a, b and R_m are influenced by the soil characteristics as well as by the regional distribution of the magnification factor. It is proposed that the expectancy of maximum earthquake motions on the structural base rock with $V_s = 0.6 \sim 0.8$ km/sec can be expressed for the long period of $6 \geq T \geq 2.0$ sec as the product of the following three factors: (1) the expectancy of maximum earthquake motions based on seismic activity on the seismic base rock with $V_s = 2 \sim 3$ km/sec, (2) the magnification factor of the ideal ground characteristics, and (3) the regional distribution of the earthquake relative to the ideal ground. The estimation for Tokyo is schematically described. It is necessary to consider that the aspect of the final regional distribution of the expectancy of earthquake motions is different from that based on the seismic base rock in the following areas: the southern part of the Kinki district, the area from the southwestern part of the Kyushu district to the southwestern port of the Shikoku district, the coastal area on the Japan Sea in the Tohoku district and so on. In addition, the effects of the soil characteristics in the short-period range ($T \leq 1.0 \sim 2.0$ sec) reflecting the shallow ground characteristics of a small area or the conception of the soil profile types should be introduced from a practical point of view.

● 3.5-2 Udaka, T., Lysmer, J. and Seed, H. B., **Dynamic response of horizontally layered systems subjected to traveling seismic waves,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 593-602.

Most currently available procedures for seismic response analyses assume that the ground just beneath the foundation, or at some depth below, vibrates in phase at all times (the rigid base concept). However, this assumption cannot be considered valid for a wide structure, since the surface ground motion is actually the result of a number of complex traveling waves. A finite element model is developed for the analysis of horizontally layered systems subjected to traveling seismic waves. The responses using the traveling wave assumption are computed for various phase velocities and compared with those computed using the rigid base assumption. The results show some interesting trends in the responses obtained using the traveling wave concept, especially in the magnitude of the normal stresses. These trends are also examined using a simple model which helps in understanding the observed responses.

● 3.5-3 Martin, G. R. et al., **Seismic response of soft offshore soils—a parametric study,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 583-592.

In this study, the effects of soil-property uncertainties on ground-response predictions at an offshore site are assessed. The site is characterized by a soft, deep cohesive soil profile. Soil parameters are determined from the results of in-situ cone penetrometer tests and laboratory cyclic triaxial and resonant column tests. Ranges in properties are assigned on the basis of observed data scatter and general experience. These ranges represent variations which can be expected given the best of conditions. Larger ranges in properties can be expected to occur when poor field and laboratory techniques are used or when no soil-property measurements are made.

● 3.5-4 Gazetas, G. and Bianchini, G., **Field evaluation of body and surface-wave soil-amplification theories,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 603-612.

This paper presents an evaluation of soil-amplification theories in the light of recorded motions at two sites in the Tokyo Bay area, Japan. Borehole accelerometers installed at various depths at these two sites have recorded motions resulting from a number of earthquakes with Richter

● *See **Preface**, page v, for availability of publications marked with dot.*

magnitudes ranging from 4.8 to 7.2 and of epicentral distances from 10 km to 320 km. Using the base accelerograms as input motions, the authors computed acceleration time-histories, response spectra, and Fourier-amplitude spectra at all the other depths and at the surface by means of body-wave or surface-wave soil amplification theories. The results are compared in this paper with the corresponding recorded accelerations and response and Fourier spectra. Conclusions are drawn regarding (1) the relative significance of soil effects, compared with the effects of different earthquake magnitudes and epicentral distances; (2) the ability to predict these effects with current amplification theories; and (3) the significance of various types of body or surface waves as functions of earthquake magnitude and epicentral distance. It must be pointed out, however, that because all the recorded motions are of rather low intensity (maximum ground accelerations less than about 0.02 g), the effects of nonlinear soil behavior are not of major concern in this investigation.

● 3.5-5 Wojcik, G. L., **Some effects of a surface dipping layer on structure and ground response in earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1114–1123.

This paper examines the role of a very simple lateral geologic inhomogeneity, the surface dipping layer, in modifying the response of both the free surface and surface structures to SH seismic input. For shallow dip angles, it is shown that zones of resonance occur over the dipping layer, where components of ground motion and structural response can be amplified by as much as an order of magnitude. The phenomenon is highly two-dimensional and contrasts strongly with results of one-dimensional amplification theory applied to a horizontal layer approximation.

● 3.5-6 Bolt, B. A. and May, T. W., **The effectiveness of trenches and scarps reducing seismic energy,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1104–1113.

In this paper, some preliminary numerical results for two-dimensional seismic barriers, as well as sharp changes in surface elevation (scarps), are presented for crustal models with horizontal layering. The finite element analysis is restricted to horizontally polarized (SH) waves and is carried out in the time domain.

● 3.5-7 Duke, C. M. and Mal, A. K., **Site and source effects on earthquake ground motion,** *UCLA-ENG-7890,* School of Engineering and Applied Science, Univ. of California, Los Angeles, Nov. 1978, 183.

This report describes a study of the effects of local site and source conditions on strong earthquake ground motions using strong-motion accelerograms and some aftershock seismograms. The instrumental data used come principally from the Managua, Nicaragua, 1972 earthquake and from three California earthquakes: Kern County, 1952; Parkfield, 1966; and San Fernando, 1971. The site data were obtained from subsurface shear wave velocity, density, and damping data properties of the soil. In executing the study, linear system theory is used, although the limitations of the theory are acknowledged. Because of the immature state-of-the-art, it is necessary to presume the predominance of body waves and to omit the effects of surface waves. Major utilization is made of Fourier transforms. In one section, existing seismological theories coupled with current knowledge of fracture mechanics are utilized to develop a comprehensive theoretical procedure for the prediction of strong ground motion at a given site. The method is applied to simple two- and three-dimensional models of earthquakes. The earthquake source is modeled by five parameters: the fault area (or length), the fault orientation (dip and strike angles), the rupture speed, the number of fault segments, and the maximum static offset across each segment. The earth in the vicinity of the source is modeled by a uniformly multilayered halfspace. The associated mathematical problem is formulated in the frequency domain by means of a representation theorem. The technique gives the body wave and surface wave contributions separately, so that their relative strengths can be compared. Attempts are made to reproduce the ground displacements and velocities recorded in the Parkfield and San Fernando earthquakes. Reasonable agreements are obtained, indicating that the technique should be useful in ground motion prediction studies. The need for further research is indicated. The influence of the source parameters on the resulting strong motion is discussed. The influence of changing layer thicknesses on surface wave motion is also investigated. Substantial use is made of linear system theory in analyzing site effects exhibited in accelerograms and aftershocks. The first method of this procedure creates subsurface models from data from field exploration. The second method, however, makes principal use of multiple accelerograms obtained in previous earthquakes. Of these methods, the first serves fairly satisfactorily in comparisons of data with analysis, while the second is less satisfactory in this respect. Both methods serve also for system identification. Comparable measurements of soil-structure interaction in earthquakes are made in several buildings in Japan and in the Hollywood Storage Building in California. These comparisons support one another and appear to support use of soil-structure interaction in design. Certain peak frequencies of strong ground motion are found to clarify the effects of site conditions on ground motion. These frequencies are the corner frequency of the source function and the predominant frequency of the surface ground motion. By estimating these two and other peak frequencies, the effects of site conditions can be better understood.

● *See **Preface**, page v, for availability of publications marked with dot.*

The study includes three evaluations of San Fernando ground motions expressed in index form. One of these expresses Arias intensity as a function of site geology. A second expresses maximum particle acceleration as a function of surface soil characteristics. In the third indicial comparison, maximum particle velocity is expressed as a function of measured subsurface shear wave velocities. The latter comparison provides the best results. In conclusion, several comparisons are made between site conditions and earthquake ground motions, some giving definitive results and others simply illuminating the site effects problem.

● 3.5-8 Griffiths, D. W. and Bollinger, G. A., **The effect of Appalachian Mountain topography on seismic waves,** *Bulletin of the Seismological Society of America,* **69**, *4*, Aug. 1979, 1081-1105.

A field program was conducted during the summer of 1977 in the Appalachian mountains to study some of the effects of topography on seismic-wave motions. The study areas included Powell Mountain (394 m of relief) in Lee County, Virginia; Bays and River Mountains (260 m of relief) in Sullivan County, Tennessee; and Gap and Brush Mountains (236 m of relief) in Montgomery County, Virginia. The majority of the data were recorded using 1 Hz horizontal seismometers aligned parallel to the long dimension of the northeast trending ridges. Some vertical (1 Hz) data were also collected. The signal sources were quarry and mine blasts located mostly to the west and northwest of the study areas. The Tennessee earthquake of July 27, 1977 (m_b (Lg) = 3.5) was recorded at Bays and River Mountains by horizontal and vertical sensors.

The basic data consist of maximum amplitudes and their associated periods measured from the *Sg-Lg* coda (some Rayleigh-wave and *P*-wave data were also obtained) at various sites on the ridges and in the valleys. In total, 137 events were considered from which 444 measurements of trace amplitude and wave period were made. These were cast as 382 amplitude ratios between the individual sites. Four of the five ridges (Powell Mountain, Gap Mountain, Bays Mountain, and River Mountain) show amplification at the mountaintops with respect to the valleys. However, one ridge, with a less pronounced crest than the others (Brush Mountain), exhibited some wave-amplitude suppression. The vertical data obtained display a lesser degree of amplification than do the horizontal data as might be expected from other published observations. To reduce the scatter found in the individual amplitude ratios, average amplitude ratios between mountaintop and valley sites were determined. These average ratios showed that the seismic wave amplitudes at the mountaintops were amplified by factors from 1.7 to 3.4. Employing the theory for scattering of *SH* waves in a halfspace with an irregular free surface, the authors obtain the predicted ground motions for each of the study areas. The comparison of the observed average ratios with these theoretical calculations indicates that a topographic effect is present but inadequately modeled by the theory.

● 3.5-9 Sanchez-Sesma, F. J. and Esquivel, J. A., **Ground motion on alluvial valleys under incident plane *SH* waves,** *Bulletin of the Seismological Society of America,* **69**, *4*, Aug. 1979, 1107-1120.

A method is presented to compute the scattering and diffraction of harmonic *SH* waves by an arbitrarily shaped alluvial valley. The problem is formulated in terms of a system of Fredholm integral equations of the first kind with the integration paths outside the boundary. A discretization scheme using line source solutions is employed and the boundary conditions are satisfied in the least-squares sense. Numerical results for amplification spectra for different geometries are presented. Agreement with known analytical solutions is excellent.

● 3.5-10 Sanchez-Sesma, F. J. and Rosenblueth, E., **Ground motion at canyons of arbitrary shape under incident SH waves,** *Earthquake Engineering & Structural Dynamics,* **7**, *5*, Sept.-Oct. 1979, 441-450.

A method for calculating the two-dimensional scattering of incident SH-waves by canyons of arbitrary shape is presented. The problem is formulated in terms of a Fredholm integral equation of the first kind with the integration path outside the boundary. Point-source discretization and a least-squares scheme are used. Numerical results are compared with the known analytic solution for a semi-cylindrical canyon. Spatial variations of surface amplitudes are computed for triangular and half-cycle sinusoidal canyons as well.

● 3.5-11 Rogers, A. M. et al., **Evaluation of the relation between near-surface geological units and ground response in the vicinity of Long Beach, California,** *Bulletin of the Seismological Society of America,* **69**, 5, Oct. 1979, 1603-1622.

Simultaneous recordings of Nevada Test Site nuclear events were made at sites underlain by alluvium in the Long Beach, California, area and at sites underlain by rock in the Palos Verdes and Pasadena areas. These data show peak ground velocity alluvium-to-rock ratios as large as 7 and spectral ratios as high as 11 in the period band from 0.2 to 6 sec. Comparison of the low-strain nuclear-explosion data and the San Fernando earthquake strong-motion data at three sites indicates that the alluvium-to-rock spectral ratios derived from the nuclear explosions are similar to those derived from the earthquake. Significant trends exist in the short-period data, indicating higher ground response at sites underlain at the near-surface by materials that have high void ratios and lower ground response with the increasing thickness of Quaternary deposits. These results suggest that the short-period response is

● *See **Preface**, page v, for availability of publications marked with dot.*

primarily controlled both by near-surface low-velocity layers and by attenuation in the Quaternary sediments. Comparison of the data of this study with data collected in other areas indicates that the long-period response increases with either increasing depth to basement or with alluvium thickness, when this thickness is greater than 400 m. From previous theoretical studies and the results of this study, ground response in the long-period band is related to those underlying geological structures and major velocity contrasts that control the development of surface waves.

● 3.5-12 Hasselman, T. K. and Eguchi, R. T., **A simple method for incorporating the uncertainty of attenuation and spectral amplification in seismic risk analysis,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 48, 14.

A simple procedure for incorporating the effects of uncertainty on both attenuation and spectral amplification, based on the lognormal distribution typically associated with data scatter, is developed. It is found that the conventional values of peak ground motion and spectral amplitude resulting from the deterministic approach, need only be multiplied by a constant to account for the uncertainty inherent in these empirical relationships. These constant uncertainty factors are provided, in graphic form, for a range of parameter values which depends on the particular uncertainties involved, the slope of the magnitude-frequency relationship, and the attenuation equations.

● 3.5-13 Wojcik, G. L., **Resonance zones on the surface of a dipping layer due to plane SH seismic input,** *Grant Report 11,* Weidlinger Assoc., New York, Jan. 1979, 89.

An analytical study is presented of the local effects of lateral geologic inhomogeneity on surface ground motion during earthquakes. The model used in the study is a surface dipping layer overlying a halfspace, with plane SH-waves incident from the halfspace in the downdip direction. Surface motion over the layer is calculated for transient (time domain) and harmonic (frequency domain) inputs. In the frequency domain, constructive interference on the surface produces a standing wave pattern with spatial zones of resonance where translational motion is on the order of 6-15 times that if the dipping layer were not present. Rotational motion is amplified to a greater extent, on the order of 20-50 times, and relative motion between spatially separated points on the order of 10-20 times. The amplification mechanism is the total reflection of multiply reflected plane waves between the free surface and the halfspace. In the time domain, a transient input is converted to a series of transients on the surface. Depending on the natural frequency and location of the layer, structural or instrumental response to a transient input is amplified to the same degree that surface motion is amplified in the frequency domain. An extension of the analysis, suitable for Love wave excitation, is described. Applications include seismic zonation, critical facility siting, building rehabilitation, and analysis of ground failure.

● 3.5-14 Werner, S. D. and Ts'ao, H. S., **Correlation of ground response spectra with modified Mercalli site intensity,** *SAN-1011-113R,* Div. of Reactor Development and Demonstration, U.S. Energy Research and Development Admin., Washington, D.C., Sept. 1978, 153.

Both the standardized spectrum shapes and the peak acceleration scaling procedures used in current practice have certain shortcomings. Therefore, the purpose of this investigation is (1) to explore alternate procedures for developing intensity-dependent criteria spectra from the complete library of strong-motion data; (2) to compare results from these procedures with spectra developed from current practice for defining seismic input criteria; and (3) to use these results as a basis for providing recommended spectra suitable for application as seismic input criteria for nuclear plants.

The procedures used in the investigation are based on an ensemble of free-field earthquake records—372 horizontal motion records and 186 vertical records—that were originally processed at the California Inst. of Technology. This ensemble is divided into various groups of records classified according to site intensity and, within each intensity grouping, according to local subsurface site conditions. Statistical analysis techniques are applied to each group of records to obtain composite spectra that correspond to selected probability levels. These spectra are then applied in three different ways. First, they are used to study the effects of site intensity and local subsurface site conditions on ground response characteristics. Second, they are compared with several methods currently used to define seismic input criteria for nuclear power plants. The methods considered in these comparisons are based on the RG 1.60 spectrum shapes; the Seed-Ugas-Lysmer spectrum shapes for different soil conditions; the Trifunac spectra for different intensities and local geologic conditions; and the current practice for defining vertical motion criteria spectra as 2/3 of the horizontal criteria spectra. Finally, the intensity-dependent spectra are used as a basis for providing spectra that are recommended for use in the seismic design of nuclear plants.

The records used in this investigation were measured only in the western United States and predominantly in California. Therefore, the results from the investigation are strictly applicable only to the West; i.e., characteristically slower intensity-attenuation rates in the East and Midwest suggest that, for a given site intensity, ground motions in these regions may differ from those represented by an ensemble of records from the western United States. Nevertheless, the seismic design of major structures in the East and Midwest has, by necessity, been based on measured

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

records from the West. This practice will continue until a sufficiently large ensemble of strong-motion records can be obtained from the East and Midwest.

● 3.5-15 Gazetas, G. and Yegian, M. K., **Shear and Rayleigh waves in soil dynamics,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15053, Dec. 1979, 1455–1470.

This paper compares the effects of Rayleigh waves to those of vertical shear waves on the dynamic response of a variety of realistic soil deposits. Using a modified version of the Thomson-Haskell-Harkrider method, the variation with depth of horizontal displacements and shear stresses resulting from the passage of the two types of waves is determined. Comparisons of their effects indicate that R- and S-waves produce similar attenuations with depth of horizontal motions, for periods close to or greater than the first natural period of the deposit in vertical shear waves, while the discrepancies observed at much shorter periods are of little practical significance since for typical soil profiles Rayleigh waves of such periods carry only a small portion of the total wave energy. However, the two waves may yield different distributions of shear stresses with depth and induce different motions of the soil particles.

● 3.5-16 Ishida, K., **Study of the characteristics of strong-motion Fourier spectra on bedrock,** *Bulletin of the Seismological Society of America,* **69,** *6,* Dec. 1979, 2101–2115.

In order to qualitatively study the Fourier spectral characteristics of strong-motion earthquake records on bedrock, the Fourier spectra of 17 accelerograms ($4.3 \leq M \leq 7.1$), which were recorded in Japan, are analyzed. The shear-wave velocities (V_S) for these records of the sites are as follows: site A1, $V_S = 1.3$ km/sec and site B1, $V_S = 1.6$ km/sec. The acceleration spectra on bedrock are estimated by statistically analyzing the above 17 accelerograms. The method of least squares is used to obtain the amplitude of the Fourier spectrum (amplitude $= a + bxT$) between period 0.1 sec and T_m sec (where $T_m = 10^{0.39M-1.7}$ sec). The distribution of coefficient $\{b\}$ is investigated. As a result of this investigation, the confidence interval for the population mean of $\{b\}$ is established. The result of this investigation suggests that the averaged Fourier amplitude spectra on bedrock can be considered to flatten statistically during the above period range. This quantitative result agrees well with the characteristics of theoretical spectra calculated by a propagating fault model. The period T_m and the corner frequency also agree well for magnitude ≥ 6.0. Kanai, in his study on the characteristics of spectra on bedrock, concluded that the velocity spectrum seemed to be flat. However, he had computed the velocity spectrum from the response of a single degree-of-freedom system. His conclusions agree quite well with the results of this study. From this paper, it can be concluded that the shape of the averaged spectra on bedrock should be flat during periods 0.1 sec and T_m sec [for magnitude < 6.0, the corner frequency should be replaced with T_m]. In other words, the results indicate that the averaged Fourier spectra of accelerograms observed at a given site should be similar to the transfer function of that site. Hence, the site-dependent spectra proposed by many investigators represent the transfer function of the site.

● 3.5-17 Chiaruttini, C., Crosilla, F. and Siro, L., **Some maximized acceleration analyses of the 1976 Friuli earthquakes,** *Bollettino di Geofisica,* **XXI,** *81,* Mar. 1979, 38–52.

In this paper, different site responses are analyzed in terms of the frequency content of the vibrations and the maximum horizontal acceleration vectors. Laws of attenuation of peak acceleration for magnitudes between 5.9 and 6.4 and relationships between peak horizontal acceleration and macroseismic intensity are presented. The preliminary results show that thin alluvial sites have a peculiar seismic response. The presence of thin, loose sediments appears to be important for the orientation of the acceleration vectors and for the typical frequency responses of such sites. The entire analysis was performed by processing the analyzed records to obtain parameters of motion which are independent of the orientation of the axes of the instruments.

● 3.5-18 Seed, H. B., **Site effects in earthquake-resistant design,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 178–204. (For a full bibliographic citation, see Abstract No. 1.2-21.)

3.5-19 Kramynin, P. I., Chernov, Yu. K. and Shteinberg, V. V., **Accelerations in rocky and loose soil in strong-motion earthquakes** (Uskoreniya kolebanii skal'nykh i rykhlykh gruntov pri sil'nykh zemletryaseniyakh, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 140–148.

Spectral analysis of accelerograms of ground motion in rocky and loose soils is used in constructing standard spectra of ground motion acceleration within and outside an epicentral zone. San Fernando 1971 earthquake data illustrate how epicentral distance affects maximum horizontal and vertical accelerations in rocky and loose soils. A weak dependence of the amplitude of accelerations in the near-field zone of strong-motion earthquakes on magnitude, epicentral distance, and soil conditions is attributed to the outward radiation from the focus of waves with short wave lengths.

3.5-20 Zarubin, N. E. and Pavlenov, V. A., **Seismic risk evaluation for slopes of excavations in rocky soil** (Ob otsenke seismicheskoi opasnosti otkosov vyemok v skal'nykh gruntakh, in Russian), *Seismichnost' i glubinnoe stroenie Pribaikal'ya,* Nauka (Siberian Division), Novosibirsk, 1978, 136–140.

● *See **Preface**, page v, for availability of publications marked with dot.*

A seismic risk evaluation is presented for slopes of excavations in rocky soils, based on the results of experimental engineering seismological field research on an area of the Baikal-Amur railway route in the U.S.S.R. An increase in seismic intensity on the brow of the slopes, relative to the basic construction site, amounts to one point or more. Changes in perceived shaking depend on the type of soil, the height and curvature of the slope, the arrival of the seismic wave, and the vibration frequency.

3.5-21 Drennov, A. F., **Experimental investigations of the effect of the thickness of unconsolidated sediments on the intensity and frequency spectrum of earthquakes** (Eksperimental'nye issledovaniya vliyaniya moshchnosti nekotorykh rykhlykh otlozhenii na intensivnost' i chastotnyi sostav zemletryasenii, in Russian), *Seismichnost' i glubinnoe stroenie Pribaikal'ya,* Nauka (Siberian Division), Novosibirsk, 1978, 140–145.

The relationship between the thickness of a layer of saturated and plastically frozen sands and earthquake intensity is discussed in relation to peak amplitudes and the corresponding periods. The speed of propagation of seismic waves and the thickness of the layer of soil are used to arrive at the most probable period in the case of loose soil and near-field earthquakes.

3.6 Seismic Site Surveys

● 3.6-1 Pikul, R. R., Wang, L. R.-L. and O'Rourke, M. J., **Seismic vulnerability of a water distribution system—a case study,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1365–1388.

This case study applies state-of-the-art earthquake engineering techniques and the results of current research developed during a National Science Foundation–sponsored project at Rensselaer Polytechnic Inst. to assess the potential vulnerability of the distribution piping system of the Latham Water District, Albany County, New York, to earthquake effects. The Latham Water District was considered typical of existing water distribution systems having a variety of pipe and joint systems reflecting the historical development of the service areas and the technology existing at the times of expansion.

Conservative analysis techniques indicate that a substantial portion of the water district could experience earthquake-related failures, based on a 450-year return period earthquake (100-year economic lifetime and a 20% probability of exceedance). The potential failure area is over a deep, loosely consolidated sand, silt, and clay area that has filled in a pre-glacial river valley to a depth of 300 to 350 feet (90 to 150 m). In addition, distribution piping in this area is of a relatively nonflexible leadite or lead joint construction, resulting in potential leakage under tensile forces.

This case study considers only wave effects and assumes that major soil failures such as landslides, faulting, and zones of soil liquefaction do not occur. Introduction of flexible joints for new portions of the system as well as replacement of damaged older portions tends to continually upgrade the system and decrease vulnerability.

● 3.6-2 Long, R. E., **The problem of estimating seismic motions,** *Engineering Design for Earthquake Environments,* Paper No. C176/78, 59–65. (For a full bibliographic citation, see Abstract No. 1.2–2.)

There are two facets to the problem of estimating seismic motions. The first facet, which is essentially a prediction problem, is determining the probability of earthquake occurrence in the vicinity of a site. The second facet is estimating the ground motions that a seismic event may be expected to produce at a site. This paper concentrates on the second of these facets. Present practice varies but generally too little care is taken in the measurement and assessment of the effect of source parameters and local geological and topographic conditions. Since these variables can alter the expected motion by an order of magnitude, their inclusion is essential to the design procedure, especially in active regions where expected peak acceleration may approach g. The problems of making an estimate based on direct site measurements are discussed.

● 3.6-3 Kulkarni, R. B., Sadigh, K. and Idriss, I. M., **Probabilistic evaluation of seismic exposure,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 90–98.

This paper describes a probabilistic model for assessing the seismic exposure of a site during a designated analysis period. The model includes several modifications to the commonly used procedures.

● 3.6-4 Marcuson III, W. F. and Krinitzsky, E. L., **Determination of design earthquake for the dynamic analysis of Fort Peck Dam,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 978–987.

Because of the slide in the Lower San Fernando Dam during the 1971 San Fernando earthquake, the U.S. Army Corps of Engineers initiated seismic studies of its hydraulic-fill structures located in seismically active areas. Fort Peck Dam is a large hydraulic-fill dam on the Missouri River in northeast central Montana. The dam was built during 1933-1940. This paper describes the investigations to determine the design earthquake used in the dynamic analysis of the dam.

● *See **Preface**, page v, for availability of publications marked with dot.*

3.6-5 Serova, G. E., **Forecasting changes in engineering seismological conditions in the development of a region** (Prognoz izmeneniya inzhenerno-seismologicheskikh uslovii pri osvoenii territorii, in Russian), *Seismichnost' i glubinnoe stroenie Pribaikal'ya,* Nauka (Siberian Division), Novosibirsk, 1978, 161-166.

Engineering geological and seismic properties of soils of several genetic types in the Goose Lake depression (south of Lake Baikal, U.S.S.R.) are studied in detail for the first time. Relations between these sets of properties are established, and the pattern of variation in properties of soils is studied with respect to effects of natural and artificial factors. Forecasts are offered for changes in the engineering seismological conditions of a region as it is developed.

● 3.6-6 Ahmed, S., Husseiny, A. A. and Cho, H. Y., **A formal methodology for acceptability analysis of alternate sites for nuclear power stations,** *Nuclear Engineering and Design,* **51**, *3*, Feb. 1979, 361-388.

A formal methodology is developed for the selection of the best sites from among alternate suitable sites for a nuclear power station. The method is based on reducing the variables affecting the decision to a single function that provides a metric for the level of site acceptability. The function accommodates selection criteria for well-known sites as well as other factors, such as public reaction to certain choices. The method is applied to the selection of a site from three acceptable alternate sites for the Wolf Creek nuclear power station in Kansas.

● 3.6-7 Ferritto, J. M., **A probabilistic evaluation of seismic loading at naval submarine base, Bangor, Bremerton, Washington,** *Technical Memorandum TM 51-79-01,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Feb. 1979, 27.

A U.S. naval regulation specifies that seismic safety studies be performed at the site of each major claimant to evaluate the overall earthquake resistance of the shore establishment. Ground acceleration and response spectra developed from the seismicity study will be used to determine the magnitude of the lateral loads on the structure. An earlier report prepared under the first phase of this work unit provides a methodology and an automated procedure for computing site seismicity studies and recurrence data needed for engineering design. The present report does not duplicate the material in the earlier report, but rather is intended as an internal working paper to document the application of the methodology to a specific site and to discuss the results.

● 3.6-8 Lew, T. K., Chelapati, C. V. and Takahashi, S. K., **Earthquake vulnerability of the Long Beach Naval Shipyard—Phase I: preliminary analysis,** *Technical Memorandum TM 51-78-09,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, May 1978, 108.

This study evaluates the seismic vulnerability of important structures at the U.S. Naval Shipyard in Long Beach, California. The study is divided into two phases. This report documents the exploratory work done in Phase I to discover existing problems and recommends directions for future investigations. The earthquake hazards at the shipyard, such as ground shaking, soil liquefaction and settlement, and tsunamis, are investigated. Selected buildings were analyzed using the rapid analysis procedure and a site response spectra developed according to the NAVFAC criteria with a maximum ground acceleration of 0.25 g. Two piers were analyzed by approximate procedures. The lifeline utilities at the shipyard were also examined.

Based on the results of the analysis performed, it is concluded that the major hazard from ground shaking is the damage it can cause to the structures, equipment, and utilities at the shipyard. Soil liquefaction at the shipyard can be expected at a maximum ground acceleration greater than about 0.1 g. Significant tsunami run-up heights at the shipyard are controlled by distant earthquakes and not local earthquakes. Tsunami damage to structures and equipment at the shipyard would consist mainly of widespread flooding. The estimated damage to the important buildings is about 72% with a return period of about 250 years. Generally, there is little or no provision for seismic bracing, support, and anchorage of nonstructural elements and contents of these buildings. Furthermore, there is generally no seismic resistance provision in the lifeline utility system of the shipyard. Earthquake damage to the lifeline utility system is expected to be about 30%.

● 3.6-9 Keeney, R. L. et al., **An evaluation and comparison of nuclear powerplant siting methodologies,** *SAND78-1284, NUREG/CR-0407,* Sandia Labs., Albuquerque, New Mexico, Mar. 1979, 231.

Methodologies for selection of nuclear power plant sites obtained from recent licensing dockets may be placed into six major categories. By means of decision analysis techniques, specific examples from each methodology were evaluated by comparison with 18 attributes of an "ideal" methodology. Site selection methodologies were applied to areas in Utah and Illinois to determine whether the different methodologies would select the same sites from among the possibilities. Results were generally consistent, although some potential sites were eliminated prematurely by selection techniques which employ exclusion principles rather than relative weighting techniques.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● **3.6-10** Ploessel, M. R. et al., **Summary of potential hazards and engineering constraints, proposed OCS Lease Sale No. 48, offshore southern California,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3398, 1979, 355-363.

Potential hazards and engineering constraints identified in proposed Outer Continental Shelf (OCS) Lease Sale Area No. 48, offshore southern California, include water deeper than 1000 ft, seafloor slopes of 4 to 70%, submarine canyons and channels, assorted mass movement phenomena, faults, possible accumulations of gas in the shallow sediments, and a locally hard and irregular seafloor. These features and conditions were identified in a reconnaissance, multi-sensor high-resolution seismic survey. Prior to developmental activities, detailed site-specific studies will be necessary to determine the potential influence of geologic features and conditions. Safe and environmentally acceptable exploration and development of possible petroleum resources appears feasible, provided the geologic and geotechnical conditions within the area are fully recognized and appropriate mitigating measures are taken to prevent potential problems.

● **3.6-11** Bilodeau, S. W., **Urban geologic problems associated with the Mixco fault zone,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 8, 21.

Portions of the rapidly expanding urban development in and west of Guatemala City were extensively ruptured by secondary faulting along the Mixco fault on Feb. 4 and 6, 1976. This fault delineates the western boundary of the Guatemala City graben and has been mapped as a series of en echelon fault traces approximately 35 km long. During the earthquakes of Feb. 1976, approximately 10 km of the fault ruptured, creating a complex pattern of ground failures over 8 km wide which affected numerous structures and transportation routes. Hazards associated with the earthquake include fault rupture, ground failure, and ground shaking. Within the fault zone are areas of residential, commercial, and industrial development as well as farm land and open space.

The physical impacts of the earthquakes and the difficulties of implementing a seismic hazard abatement program are illustrated in this paper through the study of the following three residential developments and one water filtration plant located west and northwest of Guatemala City in the vicinity of Mixco: Colonia San Francisco, a single and multiple family residential development; Colonia Carolingia, a disaster relief housing project; San Jose de las Rosas, a 2000-lot subdivision; and the Xaya Pixcaya water filtration plant Lo de Coy.

In general, the major deterrents to the effective implementation of a seismic hazard abatement program within the Mixco fault zone are related to (1) the site commitment prior to the earthquake, (2) the lack of basic geologic and fault data, (3) the lack of an official building code, (4) the lack of enforceable liability, (5) economics, and (6) public education.

In order to reduce future economic and cultural losses within the Mixco fault zone, certain basic studies involving geology, seismology, structural response, and land use planning are needed. A program for evaluating the local geologic and seismic hazard from the Mixco fault should include (1) mapping the Mixco fault in detail to determine where future ground ruptures are likely to occur; (2) evaluation of the seismicity of the fault to estimate the maximum probable and maximum credible earthquakes as well as an approximate recurrence interval; (3) evaluation of the potential ground response in relation to seismic shaking; (4) determination of the probable location of secondary ground effects such as landslides, ground lurching, liquefaction of sediments, and compaction or settlement; (5) compilation of a seismic zonation map illustrating the potential geologic effects of an earthquake on the Mixco fault. Once these data are compiled, some of the identified earthquake hazards can be greatly reduced through applied land use planning. Other economic and physical impacts could be minimized through structural design.

● **3.6-12** Kiremidjian, A. S. and Shah, H. C., **Sensitivity of the seismic hazard predictions for a site in Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 45, 15.

Ground motion values obtained through seismic hazard procedures have uncertainties resulting from the variability of the different model parameters. This paper investigates the sensitivity of peak ground motions predicted from a Poisson-based model used in the development of seismic hazard maps for Guatemala. For the purposes of analysis, a site is chosen near the Chixoy-Polochic fault. The general geologic setting near the site is reviewed with the intent to identify major geologic faults and their characteristics. The errors in the frequency of occurrence relationships are obtained and their effect on the predicted ground motion values is determined. The variations in ground motion values resulting from errors in focal depth locations are also established. Confidence bounds are obtained in each case.

● **3.6-13** Marcuson III, W. F. and Bieganousky, W. A., **Liquefaction analysis for LaCross Nuclear Power Station,** *Misc. Paper GL-79-11,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, June 1979, 41.

● *See **Preface**, page v, for availability of publications marked with dot.*

The liquefaction potential of the LaCross nuclear power plant site was evaluated for two earthquakes; namely, a safe shutdown earthquake (SSE) with a peak acceleration at the ground surface of 0.12 g, and an SSE with a peak acceleration at the ground surface of 0.2 g. The analysis was made by two methods: the Seed-Idriss simplified procedure and an empirical procedure. For a peak acceleration of 0.12 g, liquefaction is predicted by the Seed-Idriss calculations between a depth of 32 and 48 ft and liquefaction is predicted by the empirical method between a depth of 24 and 35 ft. Assuming a peak acceleration of 0.2 g, the Seed-Idriss procedure predicts liquefaction below a depth of 25 ft. The empirical method predicts liquefactions between a depth of 25 and 60 ft and between a depth of 85 and 115 ft. The soils beneath the reactor at the LaCross site are predicted to strain badly if an SSE which produces 0.12 g at the ground surface occurs. It is predicted that these soils would also experience excessive strains and liquefaction if the SSE with a peak acceleration of 0.2 g occurs. Because of the limitations in the current state of knowledge concerning liquefaction and because of the limited data for use in this analysis, it cannot be concluded that the reactor vessel foundation is safe if the 0.12 g SSE occurs. It is concluded that the reactor vessel foundation is unsafe if the 0.2 g SSE occurs.

● **3.6-14** Kiremidjian, A. S., **Seismic risk and reliability of the California State Water Project,** *Lifeline Earthquake Engineering–Buried Pipelines, Seismic Risk, and Instrumentation,* 181–198. (For a full bibliographic citation, see Abstract No. 1.2-16.)

The earthquake hazard to the California State Water Project is evaluated based on a Bayesian probability model. An iso-acceleration map for 500-year return period is developed to determine the hazard in the overall region of the lifeline system. Acceleration zone graphs are used to represent the average return period of peak ground acceleration levels at nodal points on the network system. Seismic hazard profiles map variations in peak ground acceleration levels as a function of locations along the lifeline for specified probabilities of exceedence or return periods. These graphs represent the risk-consistent design accelerations.

The risk to power plants, pumping plants, and switchyards from future earthquakes is given by the probabilities of exceeding their corresponding design levels. Power and pumping plants are designed at a horizontal peak ground acceleration level of 0.5 g, while switchyards are designed at accelerations of 0.2 g. Lower bound reliability values of branches and of the overall system are obtained with the assumption of nodal independence. Failure is defined as the interruption of water flow from the source nodes to the sink nodes. The overall system failure probabilities are initial assessments of the risk to the network.

● **3.6-15** Wheaton, R. et al., **Probabilistic evaluation of the SSE design spectrum for a nuclear power plant site: a case study,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 2/3, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This study examines the probability of exceeding the design response spectrum associated with the safe shutdown earthquake (SSE) for a nuclear power plant site in California. The study was carried out for a single fault which was considered "capable" according to U.S. Nuclear Regulatory Commission (NRC) criteria and which proved to be a controlling fault using a deterministic procedure. The purpose of the probability study was to evaluate the conservatism of the SSE design spectrum resulting from the deterministic procedure and, by implication, the conservatism of the NRC criteria for establishing fault capability. The probabilistic model developed for this study incorporates the major factors that influence seismic risk at a given site, i.e., the size and frequency of earthquakes, their location relative to the site, the attenuation of generated ground motions, and the frequency distribution of energy arriving at the site. Significant features of the model are the probabilistic treatment of much of the important input data and the use of geologic displacements rather than historic seismicity records to establish the frequency of earthquakes along the fault. The results of this study demonstrate that, for the fault considered, the SSE design spectrum recommended by the regulatory agencies is associated with an average return period in excess of 10^7 years (i.e., an annual probability of being exceeded of less than 10^{-7}). The dominant factor in these results is the extremely low earthquake recurrence rate for this fault as determined from the geologic displacement history. These findings indicate that the current regulatory criteria for determining fault capability can result in extremely conservative requirements for seismic design spectra for nuclear power plant projects.

● **3.6-16** Schlafer III, W., Tow, D. and Johnson, J. J., **Seismic response comparisons for an embedded high temperature gas-cooled reactor (HTGR) on a high seismic site,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 7/2, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The siting of nuclear power plant structures in high seismic regions has often required novel plant configurations such as oversized base slabs or deep embedment to effectively deal with the increased seismic environment. The intent of the present investigation is to analyze a high seismic risk site for a deeply embedded HTGR and compare the overall response with that obtained for a surface-founded structure sited on a wide range of potential sites.

● *See **Preface,** page v, for availability of publications marked with dot.*

The structure considered in this investigation consists of the reactor containment building (RCB) and the prestressed concrete reactor vessel (PCRV) for a representative HTGR. In the typical HTGR plant configuration, the RCB/PCRV are normally supported on a common base slab on or near the surface of the soil. A general 3-D dynamic model of the surface-founded RCB/PCRV configuration consisting of a lumped-parameter structure supported by a rigid base slab on an elastic halfspace was utilized for response calculations for each of five different soil conditions characterized by shear wave velocities of 400-8000 fps. The in-structure response spectra were determined for each site condition and combined to form a design envelope which encompasses the entire range of site parameters. The seismic excitation was defined as synthesized earthquake time histories with maximum horizontal ground accelerations of 0.15 g/OBE and 0.30 g/SSE and whose response spectra envelope the design spectra of the U.S. Nuclear Regulatory Commission Regulatory Guide 1.60.

The plant layout of the embedded HTGR functionally duplicates the corresponding surface-founded configuration with the identical RCB/PCRV embedded 88 ft. A specific high seismic risk site was selected with qualitative characteristics defined by shear wave velocities of 800-1200 fps and a maximum horizontal acceleration of 0.25 g/OBE and 0.50 g/SSE with the same synthesized time histories scaled to these higher g-levels. Using the existing 3-D lumped-parameter model of the RCB/PCRV as a basis, a 2-D plane strain finite element model was formulated. Excellent correlation of the dynamic characteristics of the 2-D and 3-D simulations was obtained through proper mass and stiffness proportioning. The deeply embedded finite element soil-structure interaction analysis was performed for mean values of the soil properties and two perturbations about the mean values. The results from these cases were enveloped to form the design parameters for the embedded HTGR and were compared to the corresponding data for a surface-founded HTGR in two principal areas: the variation of maximum acceleration within the structural configuration, and the in-structure design response spectra.

The comparison shows the maximum accelerations for the embedded configuration to be up to 50% less throughout the PCRV than for the surface-founded configuration despite the higher specified seismic environment. Similarly, the in-structure response spectra for the embedded HTGR are consistently lower than the corresponding data for the surface-founded case with peaks ranging from 1/5 to 1/2. Based upon these results, design criteria based on the surface-founded plant configuration sited on a broad range of soil conditions with a seismic environment characterized by maximum horizontal accelerations of 0.15 g/OBE and 0.30 g/SSE will encompass the embedded plant configuration of the high seismic risk site.

● 3.6-17 Davis, J. F. et al., **Technical review of the seismic safety of the Auburn damsite,** *Special Publication 54,* California Div. of Mines and Geology, Sacramento, California, May 1979, 17.

This report sets forth the general conclusions reached by the California Div. of Mines and Geology (CDMG) as a result of its analysis of the seismic design parameters of the proposed Auburn Dam. The CDMG conclusion regarding the amount of the surface fault displacement is part of the State of California position regarding the earthquake design requirements of the Auburn Dam. The discussion of the CDMG surface faulting displacement parameter is the most important segment of this report. Since this conclusion is interrelated with CDMG conclusions regarding the size of the maximum credible earthquake and the size and proximity of earthquakes that may occur at the dam site, these subjects are treated first.

● 3.6-18 Ishihara, K., Silver, M. L. and Kitagawa, H., **Cyclic strength of undisturbed sands obtained by a piston sampler,** *Soils and Foundations,* **19,** *3,* Sept. 1979, 61–76.

Undisturbed sand samples were taken from two adjacent sites in Niigata, Japan, using an Osterberg piston sampler. One site showed serious signs of liquefaction during the 1964 Niigata earthquake and the other site showed no surface signs of liquefaction. Laboratory cyclic triaxial shear tests were performed on these specimens to determine cyclic strengths of the soils in their undisturbed in-situ condition. It was found as a result of these tests that the cyclic strengths of in-situ soils in Niigata were not high. Cyclic stress ratios required to cause 5% double amplitude axial strain for 20 stress cycles were on the order of 0.2 for specimens at an average relative density of 65% and on the order of 0.15 for specimens at an average relative density of 35%. There was no distinct difference in cyclic strength values between the two sites where there was and was not surface evidence of liquefaction during the 1964 earthquake.

● 3.6-19 Borchardt, G. and Kennedy, M. P., **Liquefaction potential in urban San Diego,** *California Geology,* 32, *10,* Oct. 1979, 217–221.

This pilot investigation indicates that within urban San Diego there are areas where conditions for liquefaction could be met. First, parts of San Diego overlie sediment in which the water table is within 3 m of the surface. Second, San Diego is transected by numerous geologically youthful faults capable of producing at least moderate-sized earthquakes. Third, and most important to this study, there are sediments within San Diego that have grain size and distribution characteristics similar to those sediments with a history of liquefaction elsewhere in the world.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **3.6-20** Oweis, I. and Dobry, R., **Establishment of equivalent linear model and site period of a soil profile,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 249–279. (For a full bibliographic citation, see Abstract No. 1.2–21.)

A simplified procedure is proposed to establish the equivalent linear model of a site, needed for ground response analysis of earthquake motions. The procedure does not require the use of a computer, and it is based on a two-mode approximation of the soil profile. The equivalent model can be used to perform the response calculations by using easily available linear programs, or to compute the fundamental period of the site required by some seismic building codes.

● **3.6-21** Taylor, L. O. and Faccioli, E., **Probabilistic assessment of site dependent design spectra in Trinidad,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 205–235. (For a full bibliographic citation, see Abstract No. 1.2–21.)

The results of a seismic risk analysis are presented in this paper following Cornell's method suitably modified to allow for random uniform distribution of hypocentral depth of earthquakes. The analysis is focused on a typical site in Port-of-Spain and its results are used in the framework of recent U.S. ATC-3 (1977) recommendations to obtain a design spectrum compatible with the subsoil characteristics. The same procedure is also applied to evaluate the design spectrum at a softer nearby site (Pt. Lisas). These results are compared with those yielded by numerical ground response studies carried out in a previous paper by Taylor.

● **3.6-22** Carrillo Gil, A., **Dynamic behaviour of fluvio-alluvial soils of Lima** (Comportamiento dinamico del suelo fluvio-aluvial de Lima, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 49–56. (For a full bibliographic citation, see Abstract No. 1.2–22.)

A brief evaluation and analysis of the dynamic behavior of the fluvio-alluvial soils commonly found in the central area of the city of Lima is made. With the aid of the information, it is possible to establish semiempirical relations for evaluating, with reasonable approximation, the S-wave velocity, and with this, the shear moduli and elasticity coefficients of the conglomerate in different states such as sandy gravel and a gravel-sand-silt mix. This method provides sufficient criteria for the evaluation of the dynamic soil model useful in solving most of the practical engineering problems without the use of expensive or sophisticated instruments. Maximum safety heights are proposed for excavations and cuts in these soils, as well as in the natural slopes along the coast, and their stability when subjected to severe earthquakes is calculated by means of different methods.

3.6-23 Fotieva, N. N. and Garaichuk, V. G., **Rock stability assessment in the vicinity of tunnels and design of tunnel casings at the Rogun hydroelectric power station** (Otsenka ustoichivosti porod v okrestnosti vyrabotok i raschet obdelok tunnelei Rogunskoi ges, in Russian), *Gidrotekhnicheskoe stroitel'stvo, 5,* May 1979, 15–17.

The article cites results of calculations of the stability of rocks in the vicinity of tunnels and the stresses in tunnel casings in the Rogun hydroelectric power station in the U.S.S.R. Static loading caused by underground water and seismic response are investigated.

● **3.6-24** Wang, L. R.-L. and Lavery, W. T., **Engineering profile of Latham Water District, Albany, New York,** *Seismic Vulnerability, Behavior and Design of Underground Piping Systems, Technical Memorandum 2,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Apr. 1978, 30.

This report describes the engineering data needed for a seismic vulnerability evaluation of the Latham Water District, Albany, New York. The data needed include information about the structure of the water distribution system and the soil conditions and geological environment in the district.

● **3.6-25** Rice, S., Stephens, E. and Real, C., **Geologic evaluation of the General Electric Test Reactor site: Vallecitos, Alameda County, California,** *Special Publication 56,* California Div. of Mines and Geology, Sacramento, Aug. 1979, 19.

The purpose of this report is to provide an outline of the California Div. of Mines and Geology (CDMG) conclusions regarding the geology of the General Electric Test Reactor (GETR) site at Vallecitos, Alameda County, California. These conclusions were developed over a period of approximately two years during which time the CDMG staff conducted field investigations of its own and reviewed site-area studies undertaken by the applicant. As part of its investigations, the staff observed trench exposures that show a number of low-angle thrusts displacing sedimentary materials in the general vicinity of the GETR. The origin of these features was a major concern in these investigations.

3.6-26 Gal'perin, E. I. et al., **A study of the seismic response of large industrial centers** (Izuchenie seismicheskogo rezhima krupnykh promyshlennykh tsentrov, in Russian), Nauka, Moscow, 1978, 188.

Topics discussed include procedures and techniques for studying the seismic response of large industrial centers located in earthquake-prone regions; special attention is given to periods of seismic quiescence. Stationary observations in deep wells or boreholes (to provide compensation against normal city noise levels) make it possible to markedly upgrade equipment sensitivity, with centralized radiotelemetric recording of data, and enhanced accuracy in determining the coordinates of earthquake foci in space. Deep borehole and shallow borehole equipment is described, along with the treatment of signal and noise. The seismic environment and response at sites in the city of Alma-Ata are described on the basis of data collected for four years.

3.6-27 Geological and seismic conditions of the Baikal-Amur railway zone (Geologicheskie i seismicheskie usloviya raiona Baikalo-Amurskoi magistrali, in Russian), Nauka (Siberian Div.), Novosibirsk, U.S.S.R., 1978, 199.

The collection of papers covers a broad range of topics dealing with geological and geophysical studies of the Baikal-Amur railway construction area in the U.S.S.R. Dislocations of the sedimentary cover of the eastern portion of the Siberian platform are examined, a geological-structural analysis of the northern Baikal Lake region is presented, the relationship between the dislocations and more recent structures is discussed, geomorphological zoning is carried out, quaternary deposits are characterized, and the conditions favoring the development and propagation of exodynamic processes and of abrasion of shorelines are also covered. Some of the papers deal with hydrogeological research and seismic aspects of health resorts. Geophysical data on the structure of the earth's core and of the mantle in the northeast portion of the Baikal rift zone, and a prognostic map of the deep thermal flow in that region, are considered. Information is offered on the seismotectonics, seismicity, dynamic characteristics of seismic waves, and the mechanism underlying earthquake foci. Results of a study of seismic hazards of soils are presented, along with data from experimental investigations of railway structures subjected to conditions prevailing in the Baikal-Amur railway zone.

● 3.6-28 Novosad, S., Barvinek, R. and de la Torre Sobrevilla, M., **Study on the stability of landslide N°5 in the Tablachaca reservoir at the Mantaro hydroelectric plant** (Estudio de estabilidad del derrumbe N°5 en el reservorio de Tablachaca de la central hidroelectrica del mantaro, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering*, Vol. I, 331–344. (For a full bibliographic citation, see Abstract No. 1.2-22.)

Specific sectors of the slopes surrounding the Tablachaca reservoir, at the Antunez de Mayolo Hydroelectric Plant in Peru, which impounds the waters of the Mantaro River, are affected by landslides evident to a large degree in the sector described as "Landslide No. 5," located near the right side of the arch-gravity dam. The investigation program conducted to study the movements of the debris material included the application of geoelectric, geoacoustic, and seismic refraction investigations complemented with a detailed geologic site investigation and a topographic program of surface control measuring. The results of the field explorations have been used in the stability analysis of the landslide. The evolution of the landslide was reconstructed on the assumption of a simple mathematical model composed of a system of slip circles identified during field investigation work. The landslide development according to the mathematical model was compared to its real behavior and the validity of the assumed model was verified; this was later used to calculate the prognosis of the slope movement.

● *See **Preface**, page v, for availability of publications marked with dot.*

4. Strong Motion Seismometry

4.1 Instrumentation

● **4.1-1** Henyey, T. L. et al., **A sea-floor seismic monitoring network around an offshore oilfield platform and recording of the August 13, 1978 Santa Barbara earthquake,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3613, 1979, 2219–2223.

That it is desirable to monitor seismicity around producing oil fields in seismic regions is well established. Modifications of subsurface pore pressures, particularly during fluid injection, pose potential seismic risks. The risk is magnified in offshore areas where the consequences of spillage are potentially greater, and the mitigating steps more involved, than on land. An eight-element seismic monitoring array has been established around the Dos Cuadras offshore oil field in the Santa Barbara Channel, a highly faulted region with a history of seismicity. The array consists of five seafloor seismometers and three onshore coastal zone stations. The proper mechanical coupling of ocean-bottom seismometers to the seafloor has long been a problem. The existence of a layer of soft sediments on top of the seafloor often results in severe attenuation of the transmitted seismic waves. The authors have devised an installation method whereby the seafloor sensors are inserted into pipes vibracored 2-5 m into the seafloor where water depths range from 20 to 100 m. The sensor outputs are transmitted by seafloor coaxial cables to a central platform and then telemetered (in combination with the onshore stations) via telephone line to a recording facility in Los Angeles.

Records from the Aug. 13, 1978 (M = 5.1) Santa Barbara, California, earthquake and its aftershocks demonstrate that the method of sensor emplacement used gives superior coupling to the seafloor resulting in a record with low distortion and good signal-to-noise characteristics. The minimum detection threshold for events within the Dos Cuadras field should be on the order of M = 1.5 with epicentral locations determined to better than 1 km.

● **4.1-2** Steinmetz, R. L. et al., **Soil coupling of a strong motion, ocean bottom seismometer,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3615, 1979, 2235–2249.

A relatively economical seismic station for measuring strong earthquake-generated ground motion on the ocean bottom has recently been developed and tested. The dynamic soil-instrument interaction is a vital consideration in the development of a reliable, strong-motion measurement system that can be placed directly on the seafloor without the use of elaborate and expensive installation techniques. Experimental and analytical studies were conducted to establish the influence of soil-coupling on the response of this sensor system. Forced vibration experiments were conducted to determine the dynamic characteristics of the system and to provide a basis for calibrating and verifying an analytical model. The dynamic tests were analytically simulated and reasonable agreement with the experimental results was obtained. The analytical model was then used to further define the limits of applicability of this system and to assess its sensitivity to parameter variations. The results indicate that this sensor system will provide acceptable ground coupling in the frequency range of interest (0.1 to 10.0 Hz) and for peak acceleration levels up to 1.0 g in most cohesive-type soil conditions.

● **4.1-3** Reece, E. W. and Ryerson, D. E., **The development and demonstration of a strong motion seafloor earthquake measurement system,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. II, OTC 3462, 1979, 909–914.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

A unique instrumentation system which measures the response of marine sediments to seismic activity in remote locations has been developed and field tested. The system consists of two principal subsystems: a seafloor data-gathering package and a shipboard command and recording package. Communication between the two packages is accomplished via a high-data-rate acoustic telemetry system. The seafloor package is a totally self-contained unit. It contains a microprocessor which controls data collection, data processing, and acoustic telemetry. Sediment motions are measured with a three-axes array of force-balanced accelerometers having a dynamic range of 50 milligals to 500 gals. Accelerometer outputs are digitized at a rate sufficient to reproduce frequencies up to 20 Hz. Data are stored in a one million-bit-capacity, solid-state, nonvolatile, magnetic bubble memory. The microprocessor continuously monitors the accelerometer outputs, and is programmed to make decisions about event occurrence, event size, and data storage. The seafloor data are transmitted to the surface on command from the command and recording subsystem over the acoustic data link. With this capability, the data are available at any time during the operational lifetime of the system. In addition, the status of the seafloor package can be checked and its operating characteristics changed as necessary to gather the best data. This paper describes the design, development, and testing of the seafloor earthquake measurement system. Field test results from both onshore and offshore tests conducted in the Santa Barbara, California, area are presented and discussed. Also, future applications of the system are outlined.

● 4.1-4 Nakasugi, T. and Hashizume, M., **Observation of long period seismic waves of near earthquakes using a seismograph with natural period 5s and its stableness** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **32**, 2, June 1979, 183–190.

An observation system capable of recording the long-period components of seismic waves generated from near-field earthquakes has been constructed. A seismograph having a vertical component with a natural period of 5 sec was used. It was confirmed by repetitive, rigorous tests that the seismograph is quite stable under various conditions in a period range much longer than the natural period. A system was designed to make the observation of the longer period component as effective as possible within a specific dynamic range taking into account the characteristics of the earthquake source, the environmental conditions, the seismograph, the amplifier, and the recorder. It is expected, by using this observation system, that seismic waves of periods up to 30–50 sec can be observed for earthquakes with magnitudes smaller than 4 and at epicentral distances closer than 200 km.

● 4.1-5 Shibata, H., **On a new proposal of seismic instrumentation and trigger systems for industrial facilities,** *Lifeline Earthquake Engineering–Buried Pipelines, Seismic Risk, and Instrumentation,* 219–235. (For a full bibliographic citation, see Abstract No. 1.2–16.)

This paper considers seismic instrumentation and trigger systems for industrial facilities, such as nuclear power and petrochemical plants, oil refineries, and city gas supply systems. Instrumentation systems are usually designed for one of three purposes: verifying the vibration characteristics of structures, determining the behavior of a structure under earthquake conditions, or checking for damage after a strong earthquake. The design of the system should be modified to suit the purpose.

The design of seismic trigger systems is usually based on the design earthquake for a structure and is considered part of the safety system. The state-of-the-art of both types of systems in Japan is described.

4.2 Regional Data Collection Systems

● 4.2-1 Porter, L. D. and Real, C. R., **Data load estimation techniques for strong-motion networks,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 213–222.

● 4.2-2 Hefford, R. T. et al., **The New Zealand strong motion earthquake recorder network,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 625–642.

The network of strong-motion earthquake recorders, maintained throughout New Zealand by the Engineering Seismology Section of the Dept. of Scientific and Industrial Research, is described. The instruments are deployed either as ground instruments to measure ground motion or within structures, such as buildings, dams and industrial installations, to record structural response. Details are given of the installation of instruments, maintenance, laboratory work, record retrieval and digitization, costs, and staffing for the network. Future developments discussed include an improved digitizing system, the introduction of an improved version of the existing mechanical-optical instrument, and, in the long term, the introduction of an entirely new digital recorder having an electrical output from its accelerometers, which will make possible the transmission of data by telephone or radio.

● 4.2-3 Iwan, W. D., **The deployment of strong-motion earthquake instrument arrays,** *Earthquake Engineering & Structural Dynamics,* **7**, 5, Sept.–Oct. 1979, 413–426.

The International Workshop on Strong-Motion Earthquake Instrument Arrays was held May 2-5, 1978, in Honolulu, Hawaii. The goal of the workshop was to develop a workable plan for the possible future deployment of dense strong-motion arrays with primary emphasis on ground motion studies. Topics considered by the workshop included: favorable array locations, the design of arrays for source mechanism and wave propagation studies, the design of arrays for local effects studies, array construction and operation, and implementation. This paper summarizes the recommendations and conclusions of the workshop. Additional information on the proceedings of this meeting is available in Abstract No. 1.2-17 of Volume 8 of the *AJEE.*

● 4.2-4 Shah, H. C., Zsutty, T. C. and Khemici, O., **Development of a strong-motion instrumentation program in Algeria,** John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, June 1978, 18.

This report describes the purpose and benefits of the strong-motion instrument program for Algeria. The report also gives recommendations regarding the location and number of instruments.

● 4.2-5 Murphy, A. J. and McCann, W. R., **Preliminary results from a new seismic network in the northeastern Caribbean,** *Bulletin of the Seismological Society of America,* **69**, *5,* Oct. 1979, 1497-1513.

A network of 15 short-period seismograph stations in the northeastern Caribbean became fully operational in late 1975. The signals from the 15 seismometers are transmitted via FM radio to a central recording station on St. Thomas in the Virgin Islands. A Geotech Develocorder is being used as the principal recording device with several Helicorder records available for quick scanning for events. The network spans the region of changing tectonic style at the northeastern boundary of the Caribbean plate. On the eastern boundary, the American plate is underthrust beneath the northern Lesser Antilles; on the northern boundary, the relative motion between the plates is characterized by oblique thrusting. A principal objective in placing the network in this tectonic transition zone is to understand the nature of this transition and its impact on the problem of earthquake hazard evaluation through the analysis of microearthquake data.

The spatial pattern of small and microearthquakes recorded by the network is similar to that observed using 25 years of teleseismic data. Most of the earthquakes recorded locally and teleseismically are located between the axis of the Puerto Rican trench and the Virgin Islands platform. A few shallow earthquakes are located beneath the platform itself. The north wall of the Anegada trough, to the south of the platform, is also the site of shallow earthquake activity. As with the teleseismic data, the new hypocenters, in general, form an inclined seismic zone dipping to the south beneath the island platform and reach a depth of 125 to 150 km. There is a clear spatial correlation between the distribution of earthquakes and bathymetric features on the inner wall of the Puerto Rican trench; in particular, a prominent submarine ridge coincides with a marked change in the spatial density of earthquakes. There are striking variations in the daily rate of earthquake occurrence. A significant portion of the earthquake activity occurs as swarms. During these swarms, the daily number of events may jump one order of magnitude or more; most of these events are very shallow (<20 km), spatially clustered, and occur to the north of 19°N.

● 4.2-6 Wooton, T. M., **Strong motion instrumentation program,** *California Geology,* 32, *4,* Apr. 1979, 77-79.

● 4.2-7 McJunkin, R. D., **Strong-motion free-field site design characteristics,** *California Geology,* 32, *8,* Aug. 1979, 170-174.

● 4.2-8 Iwan, W. D., **Instrument arrays for strong ground motion studies,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 237-251. (For a full bibliographic citation, see Abstract No. 1.2-16.)

Recently, experts in earthquake engineering and seismology from all over the world met to develop a strategy for the possible future deployment of strong-motion earthquake instrument arrays with primary emphasis on ground motion studies. The results of this meeting were a series of recommendations concerning the need for strong-motion arrays, favorable locations for the deployment of such arrays, the design of arrays for source mechanism and wave propagation studies, the design of arrays for local effect studies, array construction and operation, and a plan for international coordination of array projects. This paper summarizes these recommendations and discusses the potential benefit which might be derived from the installation of strong-motion instrument arrays.

● 4.2-9 Viksne, A., **Bureau of Reclamation Strong Motion Instrumentation Program,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 265-275. (For a full bibliographic citation, see Abstract No. 1.2-16.)

The purpose of the U.S. Bureau of Reclamation Strong Motion Instrumentation Program is to obtain data on the nature of strong ground motion resulting from earthquakes and the performance of dams subjected to earthquake loading. This data provides a basis for the evaluation of the results of dynamic analysis as well as for improved design of structures located in seismically active areas. This paper reviews the various Bureau strong-motion instrument installations ranging from surface instrumentation systems to borehole-type systems with centralized recording as well as

● See **Preface,** *page v, for availability of publications marked with dot.*

digital and analog systems. It discusses the advantages of using solar power and radio time code in lieu of AC power and interconnect cables.

● **4.2-10** Anderson, J. G., Trifunac, M. D. and Teng, T. L., **Los Angeles and vicinity, California, strong motion accelerograph network: a progress report,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 277-278. (For a full bibliographic citation, see Abstract No. 1.2-16.)

The Directorate for Applied Science and Research Applications of the National Science Foundation has provided funds to establish a network of 80 free-field strong-motion accelerographs in the vicinty of Los Angeles. These instruments will be installed in such a manner as to complement the existing free-field stations installed by the California Div. of Mines and Geology strong-motion accelerograph program. The result will be 100 free-field accelerographs in the Los Angeles area. The primary objectives are to study the distribution of strong shaking, attenuation patterns of strong shaking, shear velocity structure, surface wave dispersion, and the relationship of ground motion to geologic structure and surface soils within the Los Angeles area. In Feb. 1979, instrumentation plans became final and a tentative layout for the network was completed with preliminary approvals for a large number of potential sites. This paper presents the plans for layout and instrumentation of the network, and shows how these plans will contribute to the objectives of the network.

● **4.2-11** Hart, G. C. and Rojahn, C., **A decision-theory methodology for the selection of buildings for strong-motion instrumentation,** *Earthquake Engineering & Structural Dynamics,* 7, 6, Nov.-Dec. 1979, 579-586.

Current projections indicate that six buildings per year will continue to be instrumented under the California Strong-Motion Instrumentation Program for the next several decades. In order to systematically select these buildings for instrumentation the authors have developed a methodology that incorporates the fundamental elements of decision theory. These elements include an identification of the types of buildings that should be instrumented, a definition of the expected severity of ground shaking at each possible building site along with the probability of occurrence, and a quantification of the relative value of obtaining a building-response record for each building type. Using this information, the authors apply decision theory to calculate the expected utility (degree of preference) of instrumenting buildings of a particular type at various sites. The sites are then ranked in order of preference for each building type. This procedure, developed for the California Strong-Motion Instrumentation Program, can be extended to instrumentation programs in other areas.

● **4.2-12** Berrill, J. B., **Suggested extensions of the New Zealand strong motion accelerograph network,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12**, *3*, Sept. 1979, 264-268.

The principal aim of the present network of strong-motion accelerographs in New Zealand is to record the response of structures to earthquakes, and instruments are concentrated in the larger cities where modern, tall buildings are found. However, the behavior of structures during earthquakes is now comparatively well understood. At the present time, estimating design ground motions is the weakest part in the process of designing structures to resist earthquakes. There is a strong need for more recordings of ground shaking, particularly sets of several accelerograms from single earthquakes. It is not certain that the present accelerograph network would capture any significant record of strong motion during a major earthquake in New Zealand; and the chance of a set of three or more strong accelerograms being recorded is quite small. It is recommended that 25 additional instruments be installed promptly, to fill the main gaps in the present network, and to extend the capacity of the existing local network in the Wellington area.

● **4.2-13** **Activities of the Strong Motion Instrumentation Program, August 3, 1977 to September 15, 1978,** *Special Publication 55,* Office of Strong Motion Studies, California Div. of Mines and Geology, Sacramento, 1979, 14.

This report is the first in a series to be issued on an annual basis covering the period July 1 through June 30. This report covers the period between two meetings of the Strong Motion Instrumentation Committee of the California Seismic Safety Commission on Aug. 3, 1977, and Sept. 15, 1978.

Recent earthquakes, in particular the Feb. 9, 1971, San Fernando earthquake, have called attention to the need for additional data on the response of structures and foundation materials to earthquake shaking. Increasingly intensive investigations into earthquake mechanics have demonstrated the need for data on ground response to earthquake shaking and on earthquake energy propagation effects. It is the objective of the Strong Motion Instrumentation Program to instrument representative structures and geologic settings throughout California so that significant engineering and seismological data may be collected and made available for application.

● **4.2-14** Stephenson, W. R., **Strategies for strong motion earthquake recording in New Zealand,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12**, *3*, Sept. 1979, 269-272.

● *See **Preface**, page v, for availability of publications marked with dot.*

The problem of how to record future strong earthquakes in New Zealand is examined by considering what data is required, how effective the present network will be in gathering that data, and what new technology is now available. It is concluded that present methods result in an unsatisfactory use of funds. There is a current emphasis on frequent expert servicing which, while it leads to a high probability of a recorder being in operation, restricts the number of installations able to be serviced. Thus, a high probability of a recorder being in operation is coupled with a small probability of any given earthquake being within range of a recorder. The suggested future strategy is to first develop a new accelerograph of high reliability with a self-testing capability. This would incorporate a nonvolatile electronic memory with no moving parts. Servicing of this would be at infrequent intervals, but a program of reporting the self-test results by postcard would be adopted. By thus cutting down on recorder servicing and record processing times, the major factor would be capital cost, and thus the network could expand until a realistic probability of recording a major earthquake was reached. The installation of about 70 additional strong-motion accelerographs in the main seismic region would provide a high probability that the next major earthquake would be recorded.

● **4.2-15** Shapira, A., Kulhanek, O. and Wahlstrom, R., **Detectability of regional events by means of the Swedish Seismograph Station Network,** *7-79,* Seismological Inst., Uppsala Univ., Uppsala, Sweden, 1979, 25.

A modification of the direct estimation method for threshold magnitudes, originally associated with teleseismic events, is developed. The modified approach enables one to apply the method even to weak events from regions with low seismicity such as Sweden. It is assumed that observations are supplied solely by a seismograph network located within the region. Numerical results reveal that a Swedish earthquake with a magnitude of 2.0 or larger will, with 90 percent probability, be detected by at least one station of the current Swedish Seismograph Station Network. The addition of three new stations would decrease (i.e. improve) the threshold to a magnitude of about 1.5.

5. Dynamics of Soils, Rocks and Foundations

5.1 General

● 5.1-1 Ramamurthy, T., ed., **GEOCON-India, Proceedings**, Indian Inst. of Technology, New Delhi [1978-1979], 3 vols.

The conference (also called the Conference on Geotechnical Engineering) was held in New Delhi from Dec. 20-22, 1978. Volume I contains 87 technical papers, covering the topics of foundations, soils, and earth, subsurface, and offshore structures. General and state-of-the-art reports are contained in Volume II and Volume III includes late contributions, discussions, and concluding reports. None of the papers are abstracted in this volume of the *AJEE*.

5.2 Dynamic Properties of Soils, Rocks and Foundations

● 5.2-1 Gambin, M. P., Capelle, J.-F. and Dumas, J. C., **Dynamic consolidation: a technique permitting a decrease in the risk of liquefaction of fine saturated soils in case of an earthquake** (La consolidation dynamique: une technique permettant de diminuer les risques de liquefaction de sols fins satures en cas de tremblement de terre, in French), *Third Canadian Conference on Earthquake Engineering*, Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 117-146.

Dynamic consolidation is a method for densification of loose soils to great depths by applying high-intensity impacts to the surface. Although the method has been used primarily for improving sites with poor soil conditions, thus permitting structures to be built on shallow foundations, it has also been employed to reduce the liquefaction potential of fine sands in regions of high seismic risk. In this respect, the advantage of the technique lies in increasing the relative density of the soil and the horizontal coefficient of earth pressure at rest and results in seismic "ageing" of the soil. The latter is caused by the repeated cycles of liquefaction-drainage. Three case histories of the use of dynamic consolidation are examined. The results obtained in these projects demonstrate the viability of the procedure for reducing the liquefaction potential of fine saturated sands.

5.2-2 Kim, Y. K. and Kingsbury, H. B., **Dynamic characterization of poroelastic materials**, *Experimental Mechanics*, **19**, 7, July 1979, 252-258.

This paper presents a method, based on measurement of material dynamic-complex stiffness, of determining the coefficients appearing in Biot's equations for poroelastic materials. This method is relatively simple and has several self-checking features. Results are presented and compared with theoretical predictions for material systems based on polyurethane foam, wool felt, and sand solid phases with fluid phases of water, air, and silicone fluid.

● 5.2-3 Haldar, A. and Tang, W. H., **Probabilistic evaluation of liquefaction potential**, *Journal of the Geotechnical Engineering Division, ASCE*, **105**, GT2, Proc. Paper 14374, Feb. 1979, 145-163.

A procedure is presented in this paper to estimate the probability of liquefaction for a given design earthquake magnitude and acceleration or for earthquake loading which is considered random. Reasonable comparison is obtained between the probabilities computed and field observations of liquefaction occurrences. Uncertainty analysis of the Seed and Idriss simplified method reveals that the uncertainties in the load parameters exceed those in the resistance parameters. Thus, the seismic activity of the

● *See **Preface**, page v, for availability of publications marked with dot.*

region should be given serious consideration as should the attenuation characteristics. When the maximum acceleration and earthquake magnitude are specified, the probability of liquefaction is governed by the uncertainties in the relative density and cyclic shear strength parameters. As an alternative tool of analysis, the probabilistic model could complement the deterministic procedures by providing information on the relative risk of liquefaction between design alternatives.

● **5.2-4** Mostaghel, N. and Habibagahi, K., **Cyclic liquefaction strength of sands,** *Earthquake Engineering & Structural Dynamics,* **7,** *3,* May–June 1979, 213–233.

Using an energy approach, the authors propose a model to predict the cyclic liquefaction strength of saturated sands in terms of their static shear strengths. Plots of cyclic liquefaction strength versus relative density and also versus modified standard penetration resistance are presented for various uniformity coefficients and different numbers of stress cycles. The predicted cyclic liquefaction strength values are converted to cyclic stress ratios; they compare favorably with Seed's empirical correlations.

● **5.2-5** Peck, R. B., **Liquefaction potential: science versus practice,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT3,* Proc. Paper 14418, Mar. 1979, 393–398.

Laboratory research techniques and methods of analysis have been developed in the last decade for the evaluation of the liquefaction potential of saturated sands. The procedures have been widely adopted and are now sometimes required by regulatory agencies. No direct field evidence supports the validity of the procedures. Recent tests have suggested that factors not included in the test procedures may appreciably increase resistance to liquefaction. On the other hand, field data on liquefaction have been correlated with the standard penetration resistance. Use of these empirical correlations, although crude, would have led to better practice in the last decade than reliance only on the results of the scientific studies. Scientific results may be misleading unless adequately supported by field data.

● **5.2-6** Dupas, J.-M. and Pecker, A., **Static and dynamic properties of sand-cement,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT3,* Proc. Paper 14425, Mar. 1979, 419–436.

The construction of a nuclear power plant on a liquefiable sand deposit required the treatment of the foundation. A method of treatment involving excavation and replacement with cement-stabilized sand was anticipated. An extensive laboratory testing program on different mixtures was undertaken to assess the design characteristics (static and dynamic) and to check the durability and cyclic strength of the backfill material. In the course of the testing program, it was necessary to develop new methods for interpretation of the dynamic characteristics of the soil-cement. Finally it was proved that a 5% soil-cement mixture made with ordinary portland cement is suitable.

● **5.2-7** Ohashi, M. et al., **A simplified method for assessing earthquake-induced soil liquefaction potential,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 269–280.

A simplified method for assessing the soil liquefaction potential of sandy deposits is proposed. In this method, ability of a soil deposit to resist liquefaction is represented by a liquefaction resistance factor $F_L = R/L$ in which R denotes undrained cyclic strength and L denotes earthquake-induced stress in ground. A method is proposed to estimate R from standard penetration N-values, effective overburden pressure and mean diameter. L can be estimated from the estimated maximum horizontal acceleration at ground surfaces, a reduction factor to account for deformation of the ground, soil density, and water table, according to the concepts developed by previous investigators. This simplified method is applied to various sites where liquefaction took place in the past and where appropriate geotechnical information is available. From the comprehensive studies, it is found that this simplified method is quite adequate for assessing liquefaction potential during earthquakes.

● **5.2-8** Wylie, E. B. and Henke, R., **Nonlinear soil dynamics by characteristics method,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 563–572.

The need for accurate analysis of shear wave propagation in nonlinear layered soils during seismic events is clear, and the correct application of an analysis procedure is essential in the design of earthquake-resistant structures. In 1974, the method of characteristics (MOC) applied to one-dimensional problems was shown to be a viable approach, and the program CHARSOIL was made available. As for other numerical methods, such as lumped element methods, the finite element method, and frequency domain procedures, deficiencies exist in the MOC. The designer is forced to seek a balance between limiting assumptions, complexity, accuracy, reliability, and efficiency in deciding which procedure to follow. This paper focuses on the application of the MOC and evaluates its accuracy.

The most serious shortcoming in the application of the MOC to nonlinear materials is the need for interpolations in the finite distance grid. This problem exists in any situation in which the shear modulus varies as a function of

● *See **Preface,** page v, for availability of publications marked with dot.*

strain amplitude and is of greatest concern in cases of large strain amplitude. Examples involving modulus degradation with soft clays or excess pore pressures are of particular concern. The consequence of the interpolation is numerical dispersion resulting in an unknown level of artificial energy dissipation. It should be recognized that the problem is nonexistent when one is dealing with linear materials and in transient cases involving low-amplitude strains.

Different numerical models of the MOC provide varying degrees of success in overcoming this problem. A variable time-step size greatly improves results for low-frequency excitations but provides little help in dealing with high-frequency waves. Higher order interpolations can also improve the response, but extraneous perturbations are sometimes introduced. The characteristics grid method removes the problem, but the algorithm has so many programming complexities that it is impractical. A concept of extending characteristic lines over several distance grid lines provides significant improvements in some applications, but the procedure is not practical for multilayered materials.

This study presents a concept of interpolations along the time line, rather than the depth line, in an attempt to improve upon the numerical accuracy. Additionally, an evaluation of the success of the MOC is provided by an energy calculation which compares the energy input to the soil deposit with the sum of the energy dissipated and the residual energy stored.

● 5.2-9 Charlie, W. A., Shinn, J. and Melzer, S., **Blast induced soil liquefaction,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 997–1005.

The phenomenon of blast-induced liquefaction is examined in this paper. Documented occurrences of the phenomenon, although sketchy and often incomplete, are now in the literature. Considerable work remains in using this information to develop a comprehensive method of liquefaction prediction for actual or hypothetical future blasts.

● 5.2-10 Sherif, M. A. and Ishibashi, I., **Prediction of soil liquefaction potential during earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1036–1045.

Liquefaction is defined as the total loss of soil strength when pore pressure rises to such a level that the effective in-situ overburden stresses on the soil mass are reduced to almost zero. To investigate whether a soil deposit will liquefy under an earthquake loading, prediction of the pore-pressure values developed in the soil during the earthquake is of major practical importance. Recognizing this fact, many investigators have advanced theories and procedures for predicting the time-history of pore-pressure buildup during dynamic loading. This paper explains in detail how the analytical procedure proposed earlier by the authors of this paper can be applied in practice.

● 5.2-11 Ferritto, J. M. and Forrest, J. B., **Determination of seismically induced soil liquefaction potential at proposed bridge sites,** National Technical Information Service, Springfield, Virginia, Aug. 1977, 2 vols., 439.

This technical report contains two volumes. Volume I gives a technical treatment of seismically induced liquefaction of noncohesive saturated soils. Volume II presents data in a format to be of use as an aid to bridge planners. Specific information is given to estimate earthquake motion and soil strength. Volume I is divided into nine chapters covering soil parameters which affect liquefaction, dynamic properties of soils, methods to predict liquefaction, field and laboratory methods for determining soil parameters, site earthquake motion, soil displacement consequences of liquefaction, and observed bridge damage. Volume I presents a technique for evaluation of the probability of liquefaction and possible criteria for siting of bridges. Volume II presents the results and conclusions of Volume I by reviewing alternative sites to minimize the possibility of liquefaction damage. The most important computer programs available for knowledge of the behavior of the soil at a proposed bridge site are discussed, as well as other methods of site evaluation, assessment, and selection.

● 5.2-12 Schmertmann, J. H., **Effect of shear stress on dynamic bulk modulus of sand,** *Technical Report S-78-16,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Oct. 1978, 92.

The effect of shear stress on the magnitude and directional variation of the dynamic bulk modulus of sand was investigated by laboratory measurements of P-wave and S-wave velocities under varied stress conditions. The sand used was air-dry Reid-Bedford model sand. It was tested at relative densities of about 25% and 80%. Test specimens were 4 ft high by 4 ft in diameter and were formed by pluviation in air in a cylindrical pressure chamber. At each relative density, tests were done with values of octahedral normal stress of 5, 10, and 20 psi, and with σ_3/σ_1 ratios of 1 and 1/3. Measurements of P-wave and S-wave velocities were made in three or four directions with accelerometers buried in the test specimens.

The test results indicate that compression and shear wave velocities vary with direction in an isotropic stress field because of the inherent anisotropy of the sand structure, but that this phenomenon has only a modest (0-20%) effect in producing anisotropy in the bulk modulus. The work tends to confirm, within ±10%, that the shear wave

● *See **Preface,** page v, for availability of publications marked with dot.*

velocity depends only on the level of octahedral normal effective stress and not on stress anisotropy. In contrast with the shear wave velocity, the compression wave velocity increases significantly in the direction of the major principal stress and depends primarily on the effective stress on the plane normal to wave travel. Values of bulk modulus, computed from the wave velocities under the assumption of elastic isotropy, show a variation with direction which contradicts the assumption of isotropy. Appendixes contain photographs of typical oscilloscope waveforms from each replicate series of five impacts and tables of corrected V_p and V_s (the push wave and shear wave velocities, respectively) from each test.

● 5.2-13 Martin, P. P. and Seed, H. B., **Simplified procedure for effective stress analysis of ground response,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT6,* June 1979, 739–758.

A review is made of several analytical approaches to the determination of pore-pressure generation and dissipation in saturated sands at level sites during earthquakes and the effects of the resulting pore pressure buildup on the seismic response of these sites. A simplified procedure is described that uncouples the nonlinearity of the stress-strain relationship of the sand under cyclic shear loading and the gradual stiffness degradation caused by the pore-pressure buildup under this type of loading. It was found that stress reduction between a total stress analysis, where the effective confining pressure is considered to remain constant throughout the earthquake, and an effective stress analysis that accounts for both types of soil nonlinearity, did not exceed about 85% under the most severe conditions. Consequently, it is believed that the simplified procedure may be used in conjunction with any ground-response analysis program for the purpose of evaluating ground response, including pore-pressure effects.

● 5.2-14 Drnevich, V. P. and Massarsch, K. R., **Sample disturbance and stress-strain behavior,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT9,* Sept. 1979, 1001–1016.

Different effects of sample disturbance were simulated in a resonant column apparatus. The change in stress-strain behavior was clearly shown when the sample was subjected to swelling, reconsolidation, shear strain, or total stress changes. A new framework that applies the concept of "reference strain" is suggested for considering disturbance effects on stress-strain behavior, based on results of laboratory and field measurements. The normalized behavior of a soil can be determined with high accuracy in the laboratory. By also measuring the shear strength and initial tangent modulus in the field, it is possible to accurately describe in-situ stress-strain behavior.

● 5.2-15 Roesler, S. K., **Anisotropic shear modulus due to stress anisotropy,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT7,* July 1979, 871–880.

By a special measurement technique, it is shown that the dynamic shear modulus in homogeneous isotropic sand samples depends upon the direction of stress. Furthermore, it can be demonstrated that the shear modulus is not related to the first invariant of stress tensor as assumed hitherto, but to the respective stress component itself. Measurements were performed making use of the cross correlation method and stochastic shear wave excitation by a special shear wave exciter that avoids the generation of p waves. Polarized shear waves were generated in a cubical sand sample, and the shear wave velocity was measured independent of the value and the direction of the stress in the sample. Because of the sensitivity of the correlation method, small vibration amplitudes could be applied such that a linear stress-strain relation could be assumed. It was shown that the placing technique of the sand had no influence upon the test results.

● 5.2-16 Arulanandan, K. et al., **Anisotropic sand structure related to dynamic pore pressures,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. II, OTC 3487, 1979, 1095–1104.

An effective stress theory is presented to enable the prediction of pore pressures developed in the field during cyclic loading. The theory is compared with experimental results. The electrical conductivities of sands, measured in different directions, are used to quantify the inherent anisotropy and the porosity of sands. Relations determined in the paper are used to predict the pore pressures during cyclic loading of anisotropic sand. These relations are then compared with the theory.

An effective stress theory incorporating the structure index I provided in this paper is used to predict the pore pressure development as a function of the number of cycles of loading. Experimentally measured pore pressures in a simple shear apparatus compared favorably with the theory. As it is difficult to obtain undisturbed samples of sand and as it is possible to characterize the structure index I from in situ electrical measurements, the proposed approach will have significant application in problems associated with liquefaction behavior of sands in offshore work.

5.2-17 Yaromko, V. N. and Ses'kov, V. E., **Elastic and dissipative properties of peats and organic silts** (Uprugie i dissipativnye svoistva torfov i organicheskikh ilov, in Russian), *Osnovaniya, fundamenty i mekhanika gruntov, 1,* Jan. 1979, 11–13.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Results of comprehensive studies of the dynamic properties of naturally embedded peat and organic silts covered by embankments are reported. The procedure and the equipment used in field and laboratory studies, drawing upon seismic and dynamic methods, are described. Relationships between the dynamic and physicomechanical properties of these soils are derived.

● 5.2-18 Ferritto, J. M. and Forrest, J. B., **Seismic liquefaction potential,** *Technical Note N-1530,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Sept. 1978, 187.

This report summarizes the factors causing seismically induced soil liquefaction. Currently used procedures for computing the liquefaction potential of a site are described. Risk analysis procedures are presented to better estimate the probability of liquefaction.

● 5.2-19 Mitchell, J. K., Guzikowski, F. J. and Villet, W. C. B., **Fabric analysis of undisturbed sands from Niigata, Japan,** *Technical Report S-78-11,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Sept. 1978, 112.

The fabric of two groups of undisturbed sand samples, six from a location that liquefied and five from a location that did not, from a site in Niigata, Japan, has been studied. Petrographic thin sections and water content-soil water suction measurements were used for the study. All samples were frozen after sampling but prior to transportation from the site to the laboratory. The gradational and particle shape characteristics of the medium-to-fine sands from the two locations are similar, but the void ratios of samples from the location known not to have liquefied were generally somewhat higher than for samples from the site that liquefied. Particle arrangements in the horizontal plane were slightly more random for the samples from the location that did not liquefy. These samples also exhibited a stronger degree of particle long axis orientation in vertical planes, a finding consistent to the higher resistance of these samples to liquefaction in cyclic triaxial tests. Significant differences in orientations of normals to interparticle contacts were not detected for samples from the two locations. The results of the suction-water content determinations indicated that samples from the location where the sand liquefied had a greater volume of small-sized pores than did the other samples. As the samples were not frozen until after sampling, any disturbance that may have occurred during sampling is unknown. The results do suggest, however, that fabric in situ is related to susceptibility to liquefaction.

● 5.2-20 Vaid, Y. P. and Finn, W. D. L., **Static shear and liquefaction potential,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT10,* Proc. Paper 14909, Oct. 1979, 1233–1246.

The influence of initial static shear on the undrained cyclic loading behavior of saturated Ottawa sand is studied in this paper using the new constant volume simple shear test together with improved sample preparation techniques. The generally held belief that increasing the level of static shear stress on horizontal planes progressively increases the resistance of sand to straining or liquefaction, as measured by the amplitude of cyclic stress, is not always found to be applicable. This resistance is found to increase, decrease, or remain unaltered with increase in static shear stress depending on factors such as relative density, shear strain level of interest, and the magnitude of static shear stress. However, if the cyclic loading resistance is measured in terms of the amplitude of the maximum shear stress during cyclic loading, an increase in resistance with increasing static shear stress is always noted, irrespective of the relative density or shear strain level of interest.

5.2-21 Pavlenov, V. A., Dzhurik, V. I. and Zarubin, N. E., **Field experimental research on seismic properties of hard frozen soils of the Baikal-Amur railroad zone, using explosions** (Polevye eksperimental'nye issledovaniya seismicheskikh svoistv tverdomerzlykh gruntov zony BAM s primeneniem vzryvov, in Russian), *Osnovaniya, fundamenty i mekhanika gruntov, 4,* July 1979, 18–20.

Results are reported of a study of the seismic properties of hard frozen soil in the Barguzin depression (Baikal basin). Geophysical techniques and explosions triggered in a reservoir are used to determine the properties. Deep faulting is shown to exert a pronounced effect on seismic vibrations. The damping of vibrations in hard frozen soils is determined. The spectral response of frozen and thawed soils is obtained and the related seismic hazard is evaluated.

● 5.2-22 Tatsuoka, F. et al., **Stress conditions and stress histories affecting shear modulus and damping of sand under cyclic loading,** *Soils and Foundations,* **19,** *2,* June 1979, 29–43.

To evaluate the effects of various static stress conditions and stress histories on shear modulus and damping of sand under cyclic loadings, a comprehensive series of cyclic torsional shear tests was performed on hollow cylindrical specimens of a clean sand. The following results were found. For a wide range of shear strain amplitude, the effect of stress ratio on shear modulus is minor in the triaxial compression case but considerable in the triaxial extension case. Initial shear stress decreases the shear modulus especially for the triaxial compression case. Although the shear modulus is affected by various static stress conditions, its strain-dependency is insensitive to those static stress conditions. The effects of stress ratio and initial shear stress on damping ratio are less important than shear strain amplitude and mean principal stress.

● *See **Preface,** page v, for availability of publications marked with dot.*

● 5.2-23 Ghaboussi, J. and Dikmen, S. U., **LASS-III, computer program for seismic response and liquefaction of layered ground under multi-directional shaking,** *UILU-ENG-79-2012,* Univ. of Illinois, Urbana, July 1979, 142.

In the analysis of the seismic response and liquefaction of level ground, one horizontal component of earthquake acceleration history generally is considered. The horizontal component with the higher peak acceleration is chosen for the analysis. At the present, to the authors' knowledge, no method of analysis is available for computation of seismic response and liquefaction of level ground subjected to simultaneous action of the three components of earthquake base acceleration time histories. However, it is generally recognized that the potential for liquefaction under the simultaneous action of both horizontal components of an earthquake is often higher than the liquefaction potential under the stronger horizontal component of earthquake base acceleration. This effect has been demonstrated experimentally. The surface response in a horizontally layered ground is the result of vertical propagation of two shear waves and one compression wave. The coupling and the interaction between the two horizontal components of an earthquake and the influence of the vertical component may significantly influence the character of the surface response. A new method of analysis is presented in this paper for computation of the response and the liquefaction potential of horizontally layered ground subjected to three components of earthquake base acceleration.

● 5.2-24 Nemat-Nasser, S. and Shokooh, A., **A new approach for the analysis of liquefaction of sand in cyclic shearing,** *Technical Report 78-7-11,* Earthquake Research and Engineering Lab., Northwestern Univ., Evanston, Illinois, July 1978, 17.

This work gives a fundamental systematic approach to the prediction of stress-strain relations in terms of the number of cycles and other relevant parameters. For a stress-controlled test, the strain amplitude is expressed as a function of the number of cycles, the prescribed stress amplitude, and other parameters. The results are applied to predict some of the existing experimental results, and good correlations are obtained.

● 5.2-25 Taga, N. and Togashi, Y., **Influence of elasticity of soil skeleton on dynamic properties of fluid saturated soil layer** (in Japanese), *Transactions of the Architectural Institute of Japan, 282,* Aug. 1979, 47–56.

The purpose of this paper is to investigate the dynamic properties of a saturated soil layer when the elasticity of a soil skeleton is varied. By applying the wave transfer method and the finite element method used in mixture mechanics to the soil layer, the dynamic properties of the soil layer are obtained based on the analysis of free vibration, steady-state vibration, and seismic vibration results. The results obtained are as follows: (1) The pore water in the soil affects the natural frequency and the amplification ratio in the soil layer, that is, the stiffness and damping action vary because of the elasticity of the water in the layer. (2) This water content effect is dependent on the elasticity of the soil skeleton and differs according to the type of wave propagation. (3) For shearing motion, the soil layer is softened with the increase in the elastic properties of the soil skeleton and the damping properties in the layer are increased to the same extent. (4) The water saturation in the pore for dilatational motion hardens the stiffness of the ground until the phase velocity corresponding to the propagating velocity of the water occurs in the soil skeleton; this has little effect on the properties of the layer with velocities greater than that of the water.

● 5.2-26 Raphael, J. M. and Goodman, R. E., **Strength and deformability of highly fractured rock,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT11,* Proc. Paper 14988, Nov. 1979, 1285–1300.

This paper reviews procedures used to determine properties of the greywacke sandstone forming the foundation of a concrete dam. Multistage triaxial testing of carefully reassembled core specimens provided a series of shear-strength versus normal-stress curves for fractured rock; the lowest of these was adopted as representative of the strength of the rock mass. Deformability was measured during the triaxial tests and in the field using a borehole jack in 3-in. (76-mm) drill holes. The latter yielded a value for the normal stiffness of the fractures in the rock. Introducing this stiffness value together with any given fracture spacing then determined the rock-mass modulus of elasticity corresponding to the assigned fracture spacing. Longitudinal and shear-wave velocity measurements in cross-hole configuration determined modulus of elasticity values considerably higher than those measured with the borehole jack, as expected in fractured rock.

● 5.2-27 Harada, T., Kubo, K. and Katayama, T., **Dynamic soil reactions (impedance functions) including the effect of dynamic response of surface stratum (part 3),** *Seisan-Kenkyu,* **31,** *11,* 1979, 11–13.

● 5.2-28 Ablowitz, M. J. et al., **Resonant non-linear vibrations in continuous systems—I. Undamped case,** *International Journal of Non-Linear Mechanics,* **14,** *4,* 1979, 223–233.

A method is presented for obtaining periodic solutions to forced oscillations of nonlinear systems. The method is presented by application to an equation governing the vibrations of a soil layer that is free on the top surface and is forced harmonically at the bedrock. It is shown that, unlike the discrete ODE case (Duffing equation), the continuous PDE requires an infinite number of periodicity conditions to correctly characterize the resonant region and

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

these conditions lead to an infinite number of branches in the dispersion spectrum. Calculations indicate that these branches tend to an envelope curve. The uniform approach presented by Millmann and Keller is discussed in order to determine in what sense it can be viewed as an effective approximation for the fundamental mode.

● 5.2-29 Engin, H. et al., **Resonant non-linear vibrations of continuous systems—II. Damped and transient behavior,** *International Journal of Non-Linear Mechanics,* **14,** *4,* 1979, 235–246.

The method presented in Part I (see Abstract No. 5.2–28) is extended to cover the damped and transient behavior of nonlinear systems. An application of the method is presented. Similar to the undamped case, it is again shown that the continuous PDE requires an infinite number of periodicity conditions to correctly characterize the resonant region. However, damping eliminates some of the branches of the amplitude-frequency spectrum of the undamped case. A method of multiple time scales is presented for the study of the transient behavior and the stability of the branches for steady vibrations. The stability analysis yields an interior stable point in the amplitude-frequency spectrum which has no analog in the Duffing equation. Using the multiple scale procedure which is based along the same lines as the early work of Zabusky and Kruskal, the authors obtain forced Burger and Korteweg-de Vries equations on a finite interval.

● 5.2-30 Nemat-Nasser, S. and Shokooh, A., **A unified approach to densification and liquefaction of cohesionless sand in cyclic shearing,** *Canadian Geotechnical Journal,* **16,** *4,* Nov. 1979, 659–678.

When subjected to cyclic shearing, loose dry sand densifies, and undrained saturated sand may liquefy. Based on energy considerations, a unified theory is proposed for densification and liquefaction of a homogeneous sample of noncohesive sand. It is observed that these phenomena involve rearrangement of grains in microscale, requiring an expenditure of a certain amount of energy, which increases as the void ratio approaches its minimum value and decreases as the excess pore water pressure increases. On the basis of rough estimates, explicit relations are developed for both the densification and liquefaction phenomena, and the results are applied to predict relevant available experimental data.

● 5.2-31 Townsend, F. C., **Liquefaction potential of a sand under static and dynamic loadings,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 139–150. (For a full bibliographic citation, see Abstract No. 1.2–22.)

Cyclic and monotonic loaded triaxial compression tests were performed on isotropically consolidated sand specimens for which laboratory SPT N-values were available. The objectives of these tests were (a) to provide a relationship between SPT N-values and liquefaction potential under static and dynamic loadings and (b) to examine fundamental differences between the liquefaction potential evaluated by static or dynamic loadings. Based upon these results, a first approximation relationship between SPT N-values and liquefaction potential under monotonic loadings was made. This relationship shows that cyclic tests produce 100 percent pore pressure response in specimens denser than critical. However, examination of the cyclic triaxial stress path indicates a "liquefaction-dilation" response occurs during which the stress path cycles up and down the compression and extension failure envelopes. These failure envelopes are the same for both monotonic and cyclic tests, hence the effective stress parameters define failure for both tests. To achieve 100 percent pore pressure response in cyclic tests on dense sands, the applied stress path must include stress reversals through the hydrostatic condition and application of a sufficient number of cycles.

● 5.2-32 Troncoso, J. H., **Dynamic properties of soils in tailings dams** (Propiedades dinamicas de suelos de tranques de relaves, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. I, 371–378. (For a full bibliographic citation, see Abstract No. 1.2–22.)

This paper presents results of laboratory soil dynamic tests performed on materials obtained from tailings dams. The dynamic shear modulus, damping, and cyclic strength have been determined. Testing was accomplished by means of a cyclic triaxial compression device and a shaking table.

● 5.2-33 Ishihara, K. and Takatsu, H., **Effects of overconsolidation and K_0 conditions on the liquefaction characteristics of sands,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 236–248. (For a full bibliographic citation, see Abstract No. 1.2–21.)

When overconsolidation is induced in a horizontal deposit of sand by the removal of surcharge pressure or by other events, the lateral deformation is prevented and the coefficient of earth pressure at rest, K_0, increases. To evaluate the effects of the increased overconsolidation ratio, the OCR-value, and the effects of the K_0-value on the liquefaction resistance of an overconsolidated deposit of sands, several series of cyclic torsional shear tests were carried out on samples of clean sand overconsolidated to different degrees under various K_0 conditions. The results of these tests are summarized in an empirical formula. This formula is used to estimate the cyclic strength of sand at any given OCR- and K_0-value, based on the cyclic strength for isotropically and normally consolidated samples.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● 5.2-34 Abbiss, C. P., **A comparison of the stiffness of the chalk at Mundford from a seismic survey and a large scale tank test**, *Géotechnique*, XXIX, *4*, Dec. 1979, 461-468.

Seismic velocities are calculated as a function of depth for chalk at Mundford, England, and dynamic Young moduli, which increase with depth, are found from these velocities. The moduli are compared with the results of a finite element back analysis of the settlements observed during a large-scale tank test and shown to be directly proportional. This factor is thought to be accounted for by a viscoelastic model.

● 5.2-35 Taylor, R. K. and Morrell, G. R., **Fine-grained colliery discard and its susceptibility to liquefaction and flow under cyclic stress**, *Engineering Geology*, 14, *4*, Oct. 1979, 219-229.

A spectrum of fine-grained colliery discards (tailings and slurries) has been tested in a cyclic loading triaxial rig. The granular types are shown to be the most susceptible to liquefaction, compared with the more plastic discards which exhibit a slow buildup in pore-water pressure and a gradual drop in effective stress with increasing shear strain. The plasticity index is consequently advocated as a useful physical parameter in assessing the general liquefaction potential of sediments of this type. Observations of the mobile or "flowing" discards following liquefaction suggest that effective stress is the most important determinant of apparent viscosity. The post-liquefaction behavior is believed to be pertinent to other inertial flows observed in nature.

● 5.2-36 Weaver, J. J. and Roth, W. H., **Relationship between cyclic shear strength determined by triaxial and simple shear tests**, *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering*, Vol. II, 151-161. (For a full bibliographic citation, see Abstract No. 1.2-22.)

A testing program was carried out to study the relationship between cyclic strength of soil measured by triaxial and simple shear tests. The results are interpreted to determine the correction factors required to reduce cylic triaxial strength to equivalent cyclic simple shear strength for different soil types, consolidation stresses, and failure criteria. The consolidation stresses for comparative tests were set to corresponding values of normal stress and initial shear stress on the assumed failure planes in both simple shear and triaxial specimens. Values of cyclic shear strength were then obtained from simple shear and triaxial tests with failure criteria of 4.5 and 7.5 percent single-amplitude shear strain corresponding to 3.0 and 5.0 percent axial strain. Correction factors of sands, silts, and clays for adjustment of cyclic triaxial strength to the more field-like conditions of cyclic simple shear tests are suggested. It was found that the factors vary within a range of 0.6 to 1.1 and depend on soil type, consolidation stress, number of cycles to failure, and the adopted failure criteria.

● 5.2-37 Clemence, S. P. and Mienhimer, T. L., **Study of the modulus of elasticity of a compacted soil**, *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering*, Vol. II, 353-363. (For a full bibliographic citation, see Abstract No. 1.2-22.)

The modulus of elasticity of a compacted soil was investigated using results from cyclic triaxial tests on laboratory-compacted, field-compacted samples, and field plate load tests. The soil used was a nonplastic silt compacted to a dry density of 107 pcf and moisture contents ranging from 6% to 17%. Initial moduli and cyclic reload moduli at 1/3 and 2/3 of failure stress were measured. Results indicate that the minimum amount of plastic strain occurs at moisture contents slightly drier than optimum. Field-compacted samples had initial moduli lower than laboratory-compacted specimens; however, after cycling, the moduli were approximately equal. The initial moduli from field plate load tests compared closely with the cyclic reload moduli from the laboratory tests.

● 5.2-38 Tinoco, F. H. and Sanabria Sucre, A. G., **Resonant column tests on Puerto Cabello sand** (Ensayos de columna resonante en la arena de Puerto Cabello, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering*, Vol. II, 109-137. (For a full bibliographic citation, see Abstract No. 1.2-22.)

Resonant column tests were carried out on sand from Puerto Cabello, Venezuela, to determine the influence of loading and drainage conditions on dynamic shear moduli. The objectives of this research were to: (a) analyze the influence of drainage conditions on the values of the maximum dynamic shear modulus determined under isotropic loading tests, (b) analyze the influence of anisotropic loading and drainage conditions on the values of maximum dynamic shear modulus, and (c) determine the relationship between dynamic shear modulus and shear strain for isotropic loading conditions. The results of the tests indicated that the dynamic shear modulus is an exponential function of shear strain. Anisotropic stresses increase the values of the maximum dynamic shear modulus under totally drained conditions. On the other hand, undrained conditions decrease the values of the maximum dynamic shear modulus in comparison with the values obtained under isotropic loading conditions. It was found that the pore pressures generated during the loading previous to the resonant column test produced a decrease in the values of the modulus.

● 5.2-39 Nemat-Nasser, S., **On behavior of granular materials in simple shear**, *Technical Report 79-6-19*, Earthquake Research and Engineering Lab., Dept. of Civil

● *See **Preface**, page v, for availability of publications marked with dot.*

Engineering, Northwestern Univ., Evanston, Illinois, June 1979, 31.

Simple shear deformation is considered for granular materials consisting of noncohesive rigid grains which are subjected to vertical pressure. Based on the mechanics of the relative motion of the grains or families of grains at the microlevel, and by considering the corresponding rate of frictional losses, a simple energy equation is obtained, on the basis of which the phenomena of initial densification, subsequent dilatancy for a dense sample, and the net amount of densification which accompanies cyclic shearing are explained.

● **5.2-40** Engin, H., Askar, A. and Cakmak, A. S., **An analytic method for strong motion studies in layered media,** *Research Report 79-SM-4,* Dept. of Civil Engineering, Princeton Univ., New Jersey, June 30, 1979, 64.

An analytic method is presented for calculating strong-motion spectra and the response of layered media to arbitrary input. The method is based on the removal of secular terms at resonance from the equations with polynomial nonlinearity. The nonlinear effects are introduced by frequency shifts calculated from the secular term according to the method by Millman and Keller. The procedure, through a convenient parameterization of the frequency, allows one to deal with linear equations. This possibility permits the extension of the method to multilayered systems by use of transfer matrices. The response to an arbitrary input motion is obtained from the response spectrum in the frequency domain by use of the fast Fourier transform. Such analytical methods as the Ritz-Kantorovich method, the Krylov-Bogoliubov-Mitrapolsky method, and the extension of the Duffing method by Ablowitz and the authors lead to nonlinear algebraic equations for the amplitudes. These methods would therefore be untractable in multilayered systems because they would require the solution of large, coupled nonlinear algebraic equations. The method developed is applied to wave amplification studies in geotechnical engineering. The constitutive laws are defined by the Ramberg-Osgood relationship as a backbone curve including hysteretic damping. Although the scheme is based on a method appropriate for nonlinear phenomena, the computational task remains on the order of that of a linear analysis.

● **5.2-41** De Fries, K., Prusza, Z. and Choudry, T., **Effect of compaction on the behaviour of residual soils** (Efecto de la compactacion sobre el comportamiento de suelos residuales, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 377-390. (For a full bibliographic citation, see Abstract No. 1.2-22.)

This study analyzes the effect of compaction on the behavior of residual soils derived from the decomposition of gneiss. Properties of undisturbed natural soil are compared with those of remoulded and field-compacted specimens. The following aspects have been considered: (a) shear strength, (b) compressibility and collapse, (c) permeability under various effective stresses, (d) erodibility, and (e) dynamic strength.

5.2-42 Ohara, S. and Matsuda, H., **Dynamic shear strength of saturated clay,** *Transactions of the Japan Society of Civil Engineers,* **10**, Nov. 1979, 218-220. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 274,* June 1978, 69-78.)

The experiments in this paper were carried out using a dynamic simple shear test apparatus. During the experiments, pore pressure changes, shear deformation, and shear force were recorded by a pen-recorder and the effects of the number of cycles of repeated shear stress, the sustained shear stress and the type of shear strain on the dynamic shear strength were investigated.

5.2-43 Shibata, T. and Soelarno, D. S., **Stress-strain relations of clays under cyclic loading,** *Transactions of the Japan Society of Civil Engineers,* **10**, Nov. 1979, 241-242. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 276,* Aug. 1978, 101-110.)

Many attempts have been made to obtain the analytical expression for the nonlinear stress-strain relation of soil under cyclic loading conditions, in order to simulate the influence of nonlinear soil behavior on the dynamic response of soil masses. In this paper, the Hardin-Drnevich model is discussed. The model is somewhat simplified and represents the behavior of soils under cyclic loading for which parameters have been obtained from a large amount of experimental data. A relation useful for response analysis is proposed. The stress-strain relations are discussed in terms of effective confining pressure and the initial shear modulus of clays. A new model for clays under cyclic loading is presented.

5.2-44 Yagi, N., **Volume change and excess pore water pressure in sands under repeated shear stress,** *Transactions of the Japan Society of Civil Engineers,* **10**, Nov. 1979, 232-233. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 275,* July 1978, 79-90.)

In this paper, a method is presented for the calculation of excess pore water pressures and liquefaction in sand layers during an earthquake. The excess pore water pressure and the effective stress at an arbitrary time during an earthquake are estimated. This is important because a

● *See* ***Preface****, page v, for availability of publications marked with dot.*

reduction of the effective stress leads to shear strain which may cause substantial displacements and tilting of buildings and other structures. The random shear stress waves generated during an earthquake are analyzed. The contraction characteristics of sand under cyclic shear stress are investigated since this causes liquefaction of saturated sand layers. Cyclic shear tests are carried out using simple shear and triaxial apparatus under drained conditions.

5.2-45 Pavlov, O. V., Tabulevich, V. N. and Chernykh, E. N., **The use of microseismic frequency oscillations from 0.5 to 50 Hz in estimating seismic properties of soils** (Ispol'zovanie mikroseismicheskikh kolebanii chastotoi ot 0.5 do 40 GTs dlya otsenki seismicheskikh svoistv gruntov, in Russian), *Seismichnost' i glubinnoe stroenie Pribaikal'ya*, Nauka (Siberian Division), Novosibirsk, 1978, 146–154.

An investigation is conducted of high-frequency microseisms. Magnetic tape records and frequency analyzer aids are used to trace spectra of spontaneous microseisms and the noise spectrum resulting from various natural and artificial movements and activities. Comparison of spectra of microseisms obtained at five points on the North Muya range made it possible to evaluate the seismic properties of soils.

5.2-46 Ichihara, M., Kawamura, M. and Senda, M., **Seismic passive earth pressure of cohesive soils**, *Transactions of the Japan Society of Civil Engineers*, **10**, Nov. 1979, 221–222. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 274*, June 1978, 79–94.)

The authors calculated the distribution of seismic passive earth pressures by modifying and using Sokolovski's method based on the theory of plasticity. In the calculation it is assumed that (1) the soil element is subjected to the body forces resulting from the inertia force caused by horizontal earthquake acceleration as well as gravity and (2) the stresses acting on the element satisfy the conditions of equilibrium and the criterion of failure.

5.2-47 Kagawa, T., **On the vibrational characteristics of a sand layer as a foundation model**, *Transactions of the Japan Society of Civil Engineers*, **10**, Nov. 1979, 225–228. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 275*, July 1978, 53–67.)

The major objectives of this study were to: (1) establish the validity of a suitable analytic model to simulate the dynamic behavior of a foundation soil model, and (2) provide a rational basis to perform and analyze shaking table tests on soil-structure systems by studying the vibrational characteristics of a sand layer modeled as a foundation soil.

5.3 Dynamic Behavior of Soils and Rocks

● 5.3-1 Seed, H. B., **Soil liquefaction and cyclic mobility evaluation for level ground during earthquakes**, *Journal of the Geotechnical Engineering Division, ASCE*, **105**, *GT2*, Proc. Paper 14380, Feb. 1979, 201–255.

It is shown in this paper that the design engineer has two basic choices if he considers it appropriate to neglect the possible effects of drainage occurring during the period of cyclic stress applications. His first choice is to calculate the stresses induced in the ground by the design earthquake, and to compare these stresses with those required to cause cyclic mobility or liquefaction of representative samples in the laboratory. The main problem in this approach lies in correctly assessing the characteristics of the in-situ deposit from laboratory tests performed on even, good-quality, undisturbed samples. His second choice is to be guided by the known field performance of sand deposits correlated with some measure of in situ characteristics, such as the standard penetration test. In some cases it is desirable to evaluate the possible effects of pore pressure dissipation in different layers of a deposit during and following earthquake shaking. Methods of accomplishing this are reviewed and described.

● 5.3-2 Mroz, Z., Norris, V. A. and Zienkiewicz, O. C., **Application of an anisotropic hardening model in the analysis of elasto-plastic deformation of soils**, *Géotechnique*, **XXIX**, *1*, Mar. 1979, 1–34.

This paper is an extension of an earlier work in which an anisotropic hardening model for soils was proposed. In this paper, both isotropic hardening resulting from porosity changes and anisotropy effects induced by the initial consolidation process are taken into account. The analysis is restricted to the case of the triaxial state for which two principal stresses are equal. The incremental relations are derived and applied to study the drained and undrained material behavior after isotropic and anisotropic consolidation of clays. The material response under cyclic loading is also discussed. The predicted inelastic behavior is compared with available experimental results for kaolin and Weald clays, whose material parameters are also identified. Further improvements of the model are indicated.

● 5.3-3 Aggour, M. S. and Brown, C. B., **Evaluation of methods used in the determination of dynamic earth pressure**, *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering*, New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 313–323.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

During an earthquake, many structures, such as buildings, bridges, and tunnels, are affected by the amplification of the pressure of the contiguous soil surrounding them. Several methods are available to determine these dynamic lateral earth pressures. These methods include the modification of an existing static formula for the dynamic case (Mononobe-Okabe), experiments using vibration tables, and, recently, the theory of elasticity. This paper summarizes the methods available for determining dynamic earth pressure and is a critical review of the limitations of the methods. The paper shows that indiscriminate use of the methods can lead to unsafe design of certain types of structures.

● 5.3-4 Larkin, T. J. and Donovan, N. C., **Sensitivity of computed nonlinear effective stress soil response to shear modulus relationships,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 573–582.

An analytical model is described for analyzing the response of saturated sands using effective stress parameters.

● 5.3-5 Nazarian, H. N. and Hadjian, A. H., **Earthquake-induced lateral soil pressures on structures,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT9,* Sept. 1979, 1049–1066.

Three design approaches, based on studies of the behavior of backfill soil, are available in the literature: elastic solutions, elastoplastic solutions, and fully plastic (static) solutions. The major differences in the fully plastic solutions utilizing the Mononobe-Okabe approach have been in the application point of the resultant force. Plastic solutions do not consider soil-structure interaction effects but are based on rigid body motions. Elastic dynamic solutions are proposed that provide guidelines to estimate backfill pressures for small lateral displacements. Solutions are also provided to estimate dynamic pore-water pressures. A study of the literature indicates that there is a general lack of a comprehensive treatment of the subject and a need for further investigations in the following areas for the dynamic case: passive soil pressures; elastoplastic backfill soil models; soil-structure interaction effects; mixed soils; surcharge effects; and wall stability for combined bearing, sliding, and overturning.

● 5.3-6 Erdik, M. O., **A single-degree-of-freedom model for non-linear soil amplification,** *Open-File Report 79-592,* U.S. Geological Survey, Menlo Park, California, Mar. 1979, 59.

Studies of the large-strain dynamic response of nonlinear hysteretic soil systems are indispensable for a proper understanding of soil behavior during earthquakes and an assessment of a realistic surface motion. Most of the presently available studies are based on the assumption that the response of a soil deposit is mainly caused by the upward propagation of horizontally polarized shear waves from the underlying bedrock. Equivalent-linear procedures, currently in common use in nonlinear soil response analysis, provide a simple approach and have been favorably compared with the actual recorded motions in some cases. Strain compatibility in these equivalent-linear approaches is maintained by selecting values of shear moduli and damping ratios in accordance with the average soil strains, in an iterative manner. Truly nonlinear constitutive models with complete strain compatibility have also been employed. The equivalent-linear approaches often raise doubt about the reliability of their results concerning the system response in high frequency regions. Through the use of a truly nonlinear model, it has been shown that in these frequency regions the equivalent-linear methods may underestimate the surface motion by as much as a factor of two or more.

Although several previous studies are complete in their methods of analysis, they inevitably provide applications pertaining only to a few specific soil systems and do not lead to general conclusions about soil behavior. This report attempts to provide a general picture of the soil response by using a single degree-of-freedom nonlinear-hysteretic model. Although the investigation is based on a specific type of nonlinearity and a set of dynamic soil properties, the method described is not limited to these assumptions and is equally applicable to other types of nonlinearity and soil parameters.

5.3-7 Hueckel, T. and Nova, R., **Some hysteresis effects of the behaviour of geologic media,** *International Journal of Solids and Structures,* **15,** *8,* 1979, 625–642.

A soil-mechanics–oriented theory of the hysteretic behavior of materials under alternating loading is presented. Special attention is focused on the behavior within the yield locus. The single hysteresis branches are described by piecewise path independent laws with a variable compliance matrix that depends on a scalar strain parameter. This parameter is chosen so that the polar symmetry of the unloading/reloading stress-strain curve in a uniaxial stress cycle is assured. The stress-strain constitutive laws are given either in incremental terms or in terms of finite quantities. The constitutive relations are valid piecewise within the appropriately formulated stress reversal loci. Discrete and hierarchic memory of the cyclic behavior is discussed and the rules for continuation, reactivation, or generation of subsequent laws are formulated. Simple examples are discussed.

● 5.3-8 Tokue, T., **Deformation behaviours of dry sand under cyclic loading and a stress-dilatancy model,** *Soils and Foundations,* **19,** *2,* June 1979, 63–78.

● *See **Preface**, page v, for availability of publications marked with dot.*

Cyclic shear stresses, with constant amplitudes are applied up to 1,800 cycles to a dry sand under constant overburden pressures, using a simple shear apparatus in order to clarify the factors affecting the deformation behavior. It was found that the rotation by 90 degrees of the shearing direction in the middle of a test does not affect the volume change.

● 5.3-9 Baladi, G. Y. and Rohani, B., **Development of a constitutive relation for simulating the response of saturated cohesionless soil,** *Research Report S-78-2, Liquefaction Potential of Dams and Foundations, Report 5,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1978, 59.

This report documents the development of a three-dimensional elastic-plastic isotropic constitutive model for earth materials and demonstrates the ability of the model to simulate a wide variety of observed stress-strain-pore pressure responses of fully saturated cohesionless soils. The model reproduces the hysteretic behavior exhibited by these materials when tested under hydrostatic and deviatoric states of stress, and accounts for shear-induced volume changes, strain-softening response, and progressive increases in pore pressure caused by subfailure cyclic loadings. The undrained condition for fully saturated materials is simulated by the assumption that, for each loading increment, the corresponding increment of volumetric strain is zero. The behavior of the model under simulated undrained triaxial test conditions is examined in detail and correlated with experimental data for saturated Reid-Bedford Model sand and Banding sand. It is recommended that the present constitutive model be incorporated into a suitable computer code for use in conducting numerical effective-stress analyses aimed at assessing the liquefaction potential of earth dams or other earth structures subjected to earthquake-type loadings.

● 5.3-10 Dafalias, Y. F., **A model for soil behavior under monotonic and cyclic loading conditions,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/8, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A mathematical model capable of describing soil behavior under any loading conditions, monotonic or cyclic, is presented within the framework of critical state soil mechanics. The soil is considered as an elastoplastic material without a purely elastic range. Therefore, the concept of a yield surface is completely abandoned and instead the concept of a bounding surface in a stress space, within or on which the stress state always lies, is introduced. For a given stress state, plastic strains always occur for any stress rate, except for neutral loading. The bounding surface provides the basic elements for the plastic constitutive relations as follows: (1) The direction of loading and that of the plastic strain rate are defined by the unit normal to the bounding surface at points properly defined by the given stress state and stress rate direction. (2) The value of the plastic modulus is a function of the distance, in the stress space, between the stress state and the corresponding point on the bounding surface which defines the direction of loading by means of its unit normal. The change of the size, position, and shape of the bounding surface is determined by the change of the plastic void ratio. In the course of continuous plastic loading along a fixed direction, the stress state eventually reaches the bounding surface and remains on it until failure occurs at a critical void ratio.

The concept of the bounding surface has been introduced earlier by Dafalias and Popov in conjunction with an enclosed yield surface for the cyclic behavior of metals. In this paper, the novel feature is the adaptation of a direct bounding surface plasticity formulation (without a yield surface) to account for unique characteristics of soil behavior. The model allows the qualitative description of the following phenomena: (1) the densification of lightly overconsolidated soils with increasing deviatoric stress until failure at the critical state; (2) the dilatation and unstable behavior of heavily overconsolidated soils with increasing deviatoric stress until critical failure; (3) the decrease of the mean normal effective stress and increase of pore water pressure under undrained cyclic loading of consolidated or overconsolidated soils leading to liquefaction. It should be noted that this last phenomenon for overconsolidated soils cannot be accounted for by classical yield surface soil plasticity because it does not allow for plastic strains inside the yield surface. The present formulation introduces only one additional soil parameter to those parameters used in critical state soil mechanics that are related to soil response under cyclic loading.

● 5.3-11 Hueckel, T. and Nova, R., **Hysteresis behaviour of soils and rocks,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/7, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A theory of mechanical hysteresis of geological materials under alternating loading within the yield locus is studied, with emphasis on isotropic pressure sensitivity effects. The hysteresis is described by a "secant" tensorially linear law which depends on a scalar parameter varying with the advance of the cycle. The constitutive relations are formulated piecewisely within appropriately conceived stress reversal loci. Specialization to conventional triaxial tests is considered. The feasibility of the model is examined by comparing calculated and actual test data, including those obtained in a cyclic undrained compression test.

● 5.3-12 Nemat-Nasser, S. and Shokooh, A., **On finite plastic flows of compressible materials with internal friction,** *Technical Report 79-5-16,* Earthquake Research and

● *See **Preface,** page v, for availability of publications marked with dot.*

Engineering Lab., Northwestern Univ., Evanston, Illinois, May 1979, 49.

For finite plastic deformations of porous metals and geotechnical materials such as noncohesive or cohesive soils, a theory is developed which accounts for plastic volumetric changes, pressure sensitivity, and microscopic frictional effects, and thus involves a nonassociative flow rule. This development is based on a systematic modification of the usual J_2-flow potential and yield function. It is shown that a number of specialized, recently developed plasticity theories are special cases of the theory presented here. For illustration, the problem of triaxial testing of noncohesive sands or cohesive soils is analyzed in detail, and it is shown that the theory gives many of the experimentally observed responses of this kind of materials under monotonic loading conditions. Finally, the theory is used to predict experimental results of triaxial tests of crushed granites and Ottawa sand, reported by Zoback and Byerlee, arriving at good correlation. Possible application of the theory to stable and unstable fault motions is mentioned.

● 5.3-13 Cundall, P. et al., **Computer modelling of jointed rock masses**, *Technical Report N-78-4*, Weapons Effects Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1978, 397.

This report describes work that forms part of an effort to explain and predict the phenomenon of "block motion" which can occur in jointed rock when exposed to dynamic loading. The objectives of the study were to (a) evaluate a general method for modeling jointed rock, (b) translate the original deformable element technique (DET), written in machine language, into standard FORTRAN, (c) develop a method for allowing blocks to crack and break into separate elements, and (d) conduct a review of the behavior of rock joints and develop an improved constitutive law for rock block interactions. The major objectives of the study were achieved.

A numerical scheme for treating a fully deformable block was demonstrated to give accurate results. It was shown that very little error was introduced by the calculation of sliding rock joints by means of the various rezoning schemes used. Although the new formulation is not likely to be more efficient than existing Lagrangian and finite difference codes, it was shown to have two major advantages; namely, it is completely general and can completely model any arbitrary jointing pattern and the joints are modeled accurately with no interpolation necessary at the interface.

The original rigid block program was translated into FORTRAN; the modified version is called RBM. A new idea for treating simple block deformability was developed. Each block was given three degrees-of-freedom to deform internally, with general constitutive laws given for the intact material. The method differs fundamentally from finite elements and finite differences in that it relies upon the stiffnesses of joints to link neighboring elements or zones. The new program, SDEM, is only slightly slower than the rigid block program and is useful in cases where the intact deformation of rock blocks is important but not large. A modified version of the rigid block program, RBMC, was written which allows blocks to crack and divide into separate blocks in response to the loads acting on them. A simple cracking criterion was used which was based on empirical point-load tests on irregular blocks. An extensive literature survey was made on the properties and behavior of rock joints. Based on these findings, a constitutive law was proposed for rock joints and coded into the subroutine JOINT. Listings for all programs developed under this study are provided in appendixes.

5.3-14 Nikolaevskii, V. N., **Dilatancy and laws of irreversible deformation of soils** (Dilatansiya i zakony neobratimogo deformirovaniya gruntov, in Russian), *Osnovaniya, fundamenty i mekhanika gruntov*, 5, Sept. 1979, 29-31.

An elastoplastic dilatation model of soil deformation, using limiting equilibrium conditions and proportionality of shear strain and bulk irreversible deformation, is presented. Experimental data are compared in a discussion of the nonassociativity of the flow pattern, the difference in the limiting and sub-limiting states, localization of deformations in strips, and the appearance of collapse lines. Effects of dynamics, saturation of pores with fluid, and capillary forces are pointed out. Cases are indicated for which other theories dealing with plastic deformation of soils are applicable.

● 5.3-15 Dames and Moore and Science Applications, Inc., **Study of nonlinear effects on one-dimensional earthquake response**, *EPRI NP-865*, Electric Power Research Inst., Palo Alto, California, Aug. 1978, 156.

Results of one-dimensional earthquake response computations using the nonlinear explicit finite difference computer code, STEALTH, are compared with those obtained from the equivalent linear computer code, SHAKE. Two soil profiles subjected to several input motions were studied. The nonlinear soil models used were improved derivations of models existing in the literature. Certain features of the models used were qualitatively verified with the results from dynamic soil property tests. The results from nonlinear and equivalent linear methods are in good agreement when the shear strains, and consequently, the dissipation of energy are small. For a case where larger shear strains are developed, i.e., an artificial earthquake with maximum acceleration of 0.5 g propagating vertically through 30 m (100 ft) of dry sand, the equivalent linear method overestimates peak surface accelerations by more than 150 percent and underestimates the contribution of frequencies higher than 5 Hz at the surface.

● *See **Preface**, page v, for availability of publications marked with dot.*

5.4 Dynamic Behavior of Soil and Rock Structures

● 5.4-1 Carriveau, A. R., Zanetti, J. M. and Edwards, R. B., **Dynamic longitudinal response of a buried cavity of circular cross section,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 205–221.

The longitudinal dynamic response of a two-dimensional cavity embedded in an elastic halfspace subjected to plane, horizontally polarized shear waves has been studied using an integral equation formulation. The response on the cavity surface is determined in terms of a steady-state response ratio with the response of the free surface. Results are presented for several different angles of incidence in the exciting plane wave. A shallow, an intermediately deep, and a deep cavity are studied to examine the effect of depth. Comparisons are made between the diffracted displacement field on the cavity and the incident, undiffracted field. At very low frequencies, that is, with waves the lengths of which are large compared to cavity dimensions, diffraction effects are minimal. This suggests that, for most applications, the incident field very closely approximates that which considers the diffraction effects.

● 5.4-2 Keeney, R. L. and Lamont, A., **A probabilistic analysis of landslide potential,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1016–1025.

The two objectives of this paper are to present a procedure for analyzing the risk of landslides caused by earthquakes and to illustrate the use of subjective probability assessments as a means of quantifying engineering judgments. A case study is discussed which assesses the probability of an earthquake-induced landslide at a specific site in California. The analysis was conducted using a probabilistic framework for two reasons. First, the occurrence and magnitude of earthquakes are random phenomena and a probabilistic analysis is the only way to quantify the inherent risks. Second, the evaluation of slope stability is still an uncertain science. The outcome of any such investigation is generally a judgment by the engineer which integrates the results of slope stability analysis with other pertinent information. Subjective probability assessments provide a means of quantitatively expressing these judgments and explicitly incorporating them into the overall analysis.

● 5.4-3 Abdel-Ghaffar, A. M. and Scott, R. F., **Experimental investigation of the dynamic response characteristics of an earth dam,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1026–1035.

Full-scale dynamic tests, including forced and ambient vibration as well as popper tests, were carried out on the Santa Felicia Dam in southern California subsequent to the study of the dam's earthquake response characteristics. The dam, which is instrumented with motion sensors that indicate its structural response and the input ground motion at the site, had been subjected to strong shaking during two earthquakes: the 6.3 local Richter magnitude San Fernando earthquake of 1971, and a 1976 earthquake of magnitude 4.7. The records recovered from these two earthquakes provided usable information on the dam's dynamic properties such as natural frequencies, mode shapes, dynamic shear moduli, and damping factors (the latter two as functions of the induced dynamic strains). This paper presents a description of the dynamic field test program and discusses some of the results. Included is a comparison between the dynamic properties determined from the full-scale tests and those estimated from the measured responses to the two earthquakes.

● 5.4-4 Sitar, N. and Clough, G. W., **Behavior of slopes in weakly cemented soils under seismic loading,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1006–1015.

Weakly cemented soils can be found in various geological environments throughout the world. The principal characteristics of the weakly cemented soils are their ability to stand in very steep, high natural slopes, their brittle stress-strain response at low confining pressures, and their low tensile strength. Historical records reveal that seismically induced landslides in weakly cemented soils have caused extensive economic damage and loss of life; therefore, a method of slope stability analysis for these soils is needed. The results of a field investigation indicate that failures in steep slopes of weakly cemented soils are initiated by tensile splitting and that these failures are usually quite shallow. Finite element analyses confirm this mechanism of failure.

● 5.4-5 Chaney, R. C., **Earthquake induced deformations in earth dams,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 633–642.

A method originally developed by Lee for calculating the permanent deformations induced in a saturated earth dam by an earthquake is extended to structures composed of zones of saturated, partially saturated, and dry soils. The method involves the concept that the seismic deformation of a dam results from the softened pseudo-stiffness of the soil by seismic shaking and the resultant settling of the dam

● *See* ***Preface****, page v, for availability of publications marked with dot.*

to a new condition compatible with the changed stress-strain properties of the embankment soils. The method is used to calculate the deformations of two older dams (constructed prior to 1935) and one modern dam. The three dams studied had all experienced various amounts of deformation during earthquakes in the past. A summary of the dams studied and a comparison of the observed and calculated deformations are presented in tabular form. Of the three dams studied, the direction of the calculated displacements for two of the dams (the Dry Canyon and the Lower Van Norman By-Pass in California) agreed with the observed direction of the horizontal and vertical movements. However, for one dam (Hebgen in Montana), the direction of the calculated displacements agreed for only the vertical direction. The calculations predicted a horizontal movement upstream and a small (0.8 ft) horizontal movement was observed.

● **5.4-6** Chowdhury, R. N., **Slope analysis,** *Developments in Geotechnical Engineering Vol. 22*, Elsevier Scientific Publishing Co., Amsterdam, 1978, 423.

The aims of this book are (1) to outline the fundamental principles of slope analysis and to explore the similarities and the differences in soil and rock slopes; (2) to discuss the assumptions underlying simple and so-called rigorous methods of analysis; (3) to highlight the importance of factors which influence slope performance and consider the role of progressive failure; and (4) to discuss the use of alternative methods of analysis and present information on new concepts and approaches to analysis.

● **5.4-7** Nilsen, T. H. et al., **Relative slope stability and land-use planning in the San Francisco Bay region, California,** *U.S. Geological Survey Professional Paper 944*, U.S. Government Printing Office, Washington, D.C., 1979, 96.

Landslides and associated types of slope failures such as accelerated soil and rock creep have become a major geologic hazard in the San Francisco Bay region. As increasing development of hillside areas has taken place since the mid-1940s, the costs of damage from slope failures have steadily increased. More than $1,000,000 in losses was documented from a single hillside development in the city of San Jose. For the entire San Francisco Bay region, more than $25,000,000 of damage was caused by landslides during the rainy season of 1968–69 and more than $10,000,000 in 1972–73. Such losses can be greatly reduced by (1) using geologic information to recognize, evaluate, and map those areas and slopes that are potentially unstable, and (2) applying this information in planning, designing, and organizing the use of hillside areas. For this report, we have prepared the first standardized relative slope-stabilty maps (scale 1:125,000) of the entire San Francisco Bay region. The implications and uses of these maps in the regional land-use planning process are discussed.

The land area of the region is divided into five categories and one subcategory of relative slope stability ranging from unstable to stable. The categories have been derived by analyses of the steepness of slope angles, the distribution of ancient landslide deposits, and the relative strength of bedrock and surficial geologic units. Previous studies have shown that most landslides in a given year occur on slopes greater than 15 percent (8°), in areas where landsliding has previously taken place, and in areas underlain by particular landslide-prone geologic units. Other secondary and related factors such as rainfall distribution, active seismicity, active faults, soil thickness and strength, and various effects of urbanization have not been specifically included in the analysis. However, most of these factors are incorporated in the analysis through the combined effects of slope, ancient landslide deposits, and landslide-prone geologic units.

The relative slope stability maps indicate that much of the San Francisco Bay region is relatively unstable and susceptible to natural slope failures. Unstable uplands are common in the Coast Ranges north of San Francisco Bay and in the Diablo Range east and southeast of San Francisco Bay, where steep slopes, abundant ancient landslide deposits, and weak, structurally deformed rocks of the Franciscan assemblage and Great Valley sequence, and numerous poorly consolidated younger Tertiary siltstones and shales are very susceptible to landsliding. Large parts of the Santa Cruz Mountains southwest of San Francisco Bay, underlain by Tertiary sandstones and shales, are also highly unstable. More stable areas are located in interior valleys and along the gently sloping foothills of these upland areas. However, lowlands along the margins of San Francisco, San Pablo, Suisun, and Grizzly Bays and in the Sacramento-San Joaquin delta region, underlain by soft, moist, unconsolidated muds, are unstable and susceptible to lateral flowage, particularly during earthquakes.

The relative slope stability maps have a variety of potential uses in long-range regional land-use planning for purposes such as transportation and communication networks, nuclear reactor sites, open space, and urban growth. However, because of their regional scale, they are not intended to be used for specific site investigations; these should be undertaken by qualified engineering geologists and soils engineers. The maps are designed so that in future years, as more detailed and useful data are obtained for making more sophisticated slope-stability maps (perhaps in part using computer-based technologic improvements), they will form a data base to be incorporated in the next generation of maps.

For land-use planning purposes, the six relative slope stability categories and subcategories have been subdivided into three risk groups—low, moderate, and high. Each group suggests specific actions and data requirements. These actions and data needs have been examined for three different levels of governmental concern: (1) regional, (2)

● *See **Preface**, page v, for availability of publications marked with dot.*

county and city, and (3) specific sites. Regional slope-stability analyses such as those described in this report must be supplemented by more detailed information at levels (2) and (3). At all levels of government, effective planning and land-use decisions require a continuing exchange betweeen earth scientists, planners, and engineers.

● **5.4-8** Sarma, S. K., **Response and stability of earth dams during strong earthquakes,** *Misc. Paper GL-79-13,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, June 1979, 269.

This study considers the response of an earth dam resting on a layer underlain by a rigid base and subjected to a strong ground motion. The dam and the layer are assumed to be elastic, homogeneous, and of simple geometric form. The properties of the dam and the layer may be different. Several combinations of the properties of the dam and the layer, as well as several ratios of the height of the dam to the depth of the layer, are studied. All of the combinations are subjected to nine strong-motion acceleration records, and the responses are calculated. At the same time, seismic coefficients for various sizes of sliding wedges are computed. The results of individual cases and their envelopes are presented in spectral form for design purposes.

Methods of stability analysis for static and pseudostatic conditions are examined, and two new methods are presented. One of these methods is suitable for analyzing existing slip surfaces, and the other for quick computation of the critical acceleration for a given surface. Because pore water pressure developed in the dam during an earthquake is an important factor, a method of stability analysis is developed that takes into account the excess dynamic pore water pressure. The method is based on the limit equilibrium principle. Pore water pressures are introduced in the form of a dynamic parameter. The result is obtained in the form of a critical acceleration required to cause failure as a function of the number of cycles of the earthquake load. Also shown is the computation of displacements of sliding wedges when the earthquake load is greater that the critical acceleration. The study concludes with an example of the analysis of the effects of the San Fernando earthquake of Feb. 9, 1971, on the Lopez Dam in California.

● **5.4-9** Grivas, D. A., Howland, J. and Tolcser, P., **A probabilistic model for seismic slope stability analysis,** *CE-78-5,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, June 1979, 82.

This paper provides a model for the probabilistic stability analysis of earth slopes under earthquake loading. Significant uncertainties associated with conventional pseudostatic methods of seismic stability analysis are recognized and probabilistic tools are introduced for their description and amelioration. In particular, the proposed method of analysis accounts for (a) the variability of material strength parameters, (b) the uncertainty in the exact location of potential failure surfaces, and (c) the uncertainty in the value of the maximum slope acceleration during an earthquake.

The soil material comprising the slope is assumed to be probabilistically homogeneous with strength parameters being identically distributed random variables with given statistical values. Potential failure surfaces are considered to have an exponential shape (log-spiral), defined with the aid of three random variables (two geometric parameters and the frictional strength parameter). The safety of the slope is measured in terms of its probability of failure rather than the customary factor of safety. The numerical values of the probability of failure are obtained through a Monte Carlo simulation of failure. The seismic load is introduced into the analysis through the maximum horizontal acceleration experienced by the slope during an earthquake. This is assumed to be a random variable, the probability distribution of which is found to depend on the earthquake magnitude, the type of earthquake source considered (i.e., point, line, or area source), the distance between the source and the site, and a number of regional parameters. In addition, for the purposes of this study, it is assumed that the slope is rigid, and, therefore, the maximum acceleration of the slope mass is equal to that of the ground. Two different attenuation relationships are employed to determine the maximum horizontal ground acceleration and the corresponding results are compared and discussed.

● **5.4-10** Abdel-Ghaffar, A. M. and Scott, R. F., **Shear moduli and damping factors of earth dam,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15034, Dec. 1979, 1405-1426.

In this study of an earth dam, a rational procedure is developed to estimate the dynamic soil properties of the dam, such as the shear moduli and damping factors, from the measured response of the dam to real earthquakes; the measured response includes strong-motion records from the crest and the base of the dam. The procedure permits study of nonlinear behavior by using the variation of stiffness and damping properities with strain levels. The Santa Felicia Dam, located in southern California, was chosen for the analysis because it had been subjected to strong shaking during two earthquakes (with M_L=6.3 and 4.7), and was equipped with strong-motion instruments that yielded data on the structural response as well as data on the input ground motion at the site. The investigation is limited to the upstream-downstream response since existing analytical techniques for earth dams are restricted to horizontal shear deformation in that direction.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **5.4-11** Abdel-Ghaffar, A. M. and Scott, R. F., **Analysis of earth dam response to earthquakes,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15033, Dec. 1979, 1379–1404.

An investigation has been made of the effect of two earthquakes with Richter local magnitudes M_L of 6.3 and 4.7 on a modern rolled-fill earth dam in southern California. The dam was equipped with motion sensors that yielded data on the structural response as well as data on the ground input motion at the site. Amplification spectra of the dam were computed for the two earthquakes to indicate the natural frequencies of the dam, to estimate the shear-wave velocity of its materials, and to estimate the relative contribution of different modes of vibrations. A comparison between the aforementioned natural frequencies and those obtained for the dam by existing shear-beam theories was made to obtain representative dam material properties. In addition, field wave-velocity measurements were carried out as a further check as well as to study the variation of shear-wave velocity (or shear modulus) at various depths below the crest of the dam.

● **5.4-12** Makdisi, F. I. and Seed, H. B., **Simplified procedure for evaluating embankment response,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15055, Dec. 1979, 1427–1434.

For many types of embankments, constructed of dry or very dense sands or clayey soils, an estimate of the magnitude of the deformations which might be induced by earthquake shaking can be made from a knowledge of the yield acceleration for a potential sliding mass, the maximum acceleration induced at the crest of the dam by the earthquake, and the natural period of vibration of the dam. The yield acceleration, i.e., the average acceleration at which a condition of incipient failure is induced in the potential sliding mass, is determined by the strength parameters of the soil and an appropriate method of stability analysis. A simplified procedure, which enables the determination by hand calculation, of the maximum crest acceleration and the natural period of an embankment caused by a specified earthquake loading is described in this paper. The method also allows, through iteration, the use of strain-dependent material properties.

● **5.4-13** Sarma, S. K., **Stability analysis of embankments and slopes,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15068, Dec. 1979, 1511–1524.

In this paper, the limit equilibrium method of stability analysis of embankments and slopes is considered in terms of the indeterminacy of the problem. At the same time, various assumptions for making the problem a determinate one are also considered. A method of stability analysis is proposed. It shows that the shear strength on internal shear surfaces has an effect on the computed factor of safety. This method is useful in analyzing actual slips in nature. In the example case, it produces results compatible with those arising from the plasticity theory.

● **5.4-14** Grivas, D. A., **Program RASSUEL: reliability analysis of soil slopes under earthquake loading,** *CE-78-6,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Dec. 1978, 41.

RASSUEL is a computer program developed to assess the reliability of soil slopes under earthquake loading. A pseudostatic slope stability analysis is performed. Significant uncertainties in material and seismic parameters are recognized and probabilistic tools are introduced for their description and amelioration. The safety of the slope is measured in terms of its probability of failure rather than the customary factor of safety. The numerical values of the probability of failure are obtained through a Monte Carlo simulation of failure. The program can accommodate three types of earthquake source, namely, a point source, a line source, and an area source. A detailed presentation of the theoretical background of this program can be found in the first report of this series, RPI Report CE-78-5. The present document includes a brief description of the program and its capabilities. The various functions and options available in the program are presented in the form of a flow chart. Guidelines for data preparation are given in Appendix A. The program was written for an IBM 3033 computer. Special provisions were made so that it can be easily adjusted for use on CDC hardware. The computer graphics option was written for a PRIME 500 computer. In Appendix B are listed the subroutines that are required for use of the program on a PRIME 500 computer and for the computer graphics option. A complete listing of the program is given in Appendix C.

To illustrate the output provided by the program, the program was applied in a case study involving the determination of the probability of failure of a slope during a seismic event. The earthquake source was assumed to be a fault (line source) of known geometry and distance from the site of the slope.

● **5.4-15** Banerjee, N. G., Seed, H. B. and Chan, C. K., **Cyclic behavior of dense coarse-grained materials in relation to the seismic stability of dams,** *UCB/EERC-79/13,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 283. (NTIS Accession No. PB 301 373)

The report presents the results of a comprehensive cyclic triaxial test program conducted on a modeled rockfill material with the intent of simulating as closely as possible

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

the field loading conditions developed during an earthquake on a coarse-grained soil. gradation with 2-in. maximum particle size was used for the 12-in. diameter specimens tested. Necessary design modifications were incorporated in the test facilities to accommodate a wide range of test pressures. Sustained pressure tests, conducted to simulate the aging effect in a prototype structure showed very significant increases in cyclic resistance in a relatively short period of 2 1/2 months when compared to data for normally consolidated samples tested immediately after compaction. After correcting the basic test data for aging effects, the test results were reduced to a usable form for performing a seismic stability analysis of the 770-ft-high Oroville gravel-fill dam in California for a magnitude 6.5 earthquake which might possibly occur near the dam and also for a hypothetical earthquake of magnitude 8 1/4 occurring on a fault close to the dam. The analyses showed that the anticipated permanent deformations of the dam caused by earthquakes of magnitudes in the range 6.5 to 8.25 would be acceptable. These findings, however, do not preclude the possibility of surface raveling of loose gravel near the crest—a phenomenon which is not considered of great significance from a structural integrity point of view.

● 5.4-16 Prieto-Portar, L. A. and Velarde S. M., J. L., **Seismic stability of a proposed 55 meter high tailings dam at Chicrin, Peru,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. I, 345-370. (For a full bibliographic citation, see Abstract No. 1.2-22.)

This paper proposes a solution to the massive tailings disposal problem of the Atacocha mines, analyzes the seismic stability of the dam, and outlines some design and construction recommendations.

● 5.4-17 Grivas, D. A. and Nadeau, G., **Probabilistic seismic stability analysis: a case study,** *CE-79-1,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, July 1979, 34.

This study provides an application of a probabilistic seismic stability analysis to a natural slope located near Slingerlands, New York. The safety of the slope is measured in terms of its probability of failure rather than the customary factor of safety. Three types of earthquake sources are investigated, namely, a point, a line, and an area source, and the dependence on significant seismic parameters of the probability of failure of the slope is examined. On the basis of the results obtained in this study, it is concluded that (a) the present model is useful in assessing the reliability of soil slopes under both static and seismic conditions, and (b) the probability of failure of a soil slope is greatly affected by the type of the earthquake source involved and by the values of seismic parameters that are associated with it.

5.4-18 Kagawa, T., **On the similitude in model vibration tests of earth structures,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 229-231. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 275,* July 1978, 69-77.)

This paper presents a new similitude method that may be used to investigate nonlinear vibration characteristics of earth and soil-structure systems. The proposed method assumes a normal gravity field and the use of the same soils for both model and prototype, and involves the scaling of stresses and strains according to the strain-dependent nonlinearity of soils. Thus, the similitude provides an improved means of studying prototype behavior through model vibration tests.

● 5.4-19 Voight, B., ed., **Rockslides and avalanches: 1. Natural phenomena; 2. Engineering sites,** *Developments in Geotechnical Engineering 14 A-B,* Elsevier Scientific Publishing Co., Amsterdam, 1978-1979, 2 vols., 1683.

Rockslides and avalanches provides a foundation for studies of mass movement phenomena in the Western Hemisphere. The volumes are multiple-authored, containing 48 contributions from 70 authors. Also included are a subject index and a references index.

5.5 Dynamic Behavior of Foundations, Piles and Retaining Walls

● 5.5-1 Kuhlemeyer, R. L., **Static and dynamic laterally loaded floating piles,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT2,* Proc. Paper 14394, Feb. 1979, 289-304.

A previously formulated beam bending finite element of circular cross section is presented to obtain an economical solution to the three-dimensional problem of static and dynamic laterally loaded piles embedded in elastic media. The general solution is almost solely a function of the ratio of Young's modulus (E) of the pile divided by E of the soil; neither Poisson's ratio of the soil nor the mass density of the pile are important for practical application purposes. Static loading results are presented in the form of flexibility coefficients for a range of two-layer soil systems. The dynamic loading fundamental solution for a pile embedded in an elastic halfspace is presented in terms of the static solution multiplied by the associated complex frequency-dependent factors. Since this static solution can be presented as a linear relationship between the logarithm of the flexibility coefficient and the logarithm of Young's moduli ratio, both the static and dynamic solutions can be approximated by a simple closed-form expression.

● *See **Preface,** page v, for availability of publications marked with dot.*

● **5.5-2** Prakash, S. and Nandakumaran, P., **Earth pressures during earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 613–622.

In connection with the design of retaining walls approximately 80 ft high for the Beas Dam (India), a comprehensive model study was carried out to determine the point of application of the components of the "total" earth pressures. Earth pressures were also measured under static and dynamic conditions. A brief description of the model test and the results are presented along with an examination of the performance of a retaining wall in the Koyna earthquake of Dec. 11, 1967.

● **5.5-3** Aggour, M. S., **Dynamic earth pressure determination,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 55, 11.

This paper formulates a mathematical model for a wall-backfill-foundation system. With such a model, the physical and mechanical properties of both the soil and the structure are considered in the evaluation of the vibrational characteristics and seismic response of the system. The finite element method is used to calculate the stress, strain, and deformation of the system. The results of this study indicate that the dynamic pressure varies markedly depending upon the properties of the soil and the structure, their geometry, and their loading. The results also show that indiscriminate use of the Mononobe-Okabe formula can lead to the unsafe design of certain types of structures. The formula, a limit design method, does not indicate the normal equilibrium stress or strain state produced in a system.

5.5-4 Bakholdin, B. V. and Sturov, V. I., **Short-term loads in the design of pile foundations** (Ob uchete kratkovremennykh nagruzok pri proektirovanii svainykh fundamentov, in Russian), *Osnovaniya, fundamenty i mekhanika gruntov,* 5, Sept. 1979, 14–15.

Results are reported of tests on stand-alone piles in clayey soils subjected to a variety of short-term and constant loads. It is shown that cyclic application of short-term loads leads, under all conditions, to appreciable residual settlement of the piles, and that settling of the piles diminishes rapidly when a time-constant load equal to the sum of a short-term load and a constant load is applied.

● **5.5-5** Reese, L. C., **Design and evaluation of load tests on deep foundations,** *Behavior of Deep Foundations,* 4–26. (For a full bibliographic citation, see Abstract No. 1.2–23.)

The use of methods of prediction of the performance of deep foundations is strongly encouraged. The paper presents models for both axially loaded and laterally loaded deep foundations and shows examples of the use of the models. Internal instrumentation that can be used in future load tests is discussed, along with load test procedures. Information from load tests of instrumented deep foundations will allow improvements in the methods of prediction of the behavior of deep foundations under various kinds of loading.

5.6 Experimental Investigations

5.6-1 Larkin, T. J. and Taylor, P. W., **Comparison of down-hole and laboratory shear wave velocities,** *Canadian Geotechnical Journal,* **16,** *1,* Feb. 1979, 152–162.

The down-hole seismic surveying method is described. This method was successfully used to a depth of 50 m in a cased borehole. The results are described. The method may be used to find the in-situ, low-strain shear modulus for use in theoretical response studies. Structural changes and changes in the stress state of samples usually result from sampling, handling, and testing procedures. Large changes in soil properties may result from these processes. An assessment of the change in soil properties is presented, which is of importance for the use of laboratory-derived soil properties in theoretical in-situ dynamic response studies.

The magnitude of sample disturbance is assessed by comparing in-situ and laboratory-measured shear wave velocities. In-situ downhole shear wave velocities are compared with low strain (1×10^{-6}) laboratory dynamic torsion test results. The large differences found may be correlated with the in-situ shear wave velocity. A procedure is presented to correct the laboratory-established shear modulus-strain relationship for the effects of sample disturbance. The adjusted laboratory curve is then suitable for use in theoretical response studies and will be a more accurate representation of the in-situ deformation characteristics.

5.6-2 Lee, K. L., **Cyclic strength of a sensitive clay of eastern Canada,** *Canadian Geotechnical Journal,* **16,** *1,* Feb. 1979, 163–176.

Cyclic loading tests were performed on many undisturbed and a few compacted specimens of two samples of very sensitive clay from an earth dam site on the Outardes River in Quebec. Failure occurred when one or more thin shear zones developed in which the remolded soil was reduced to a liquid, while the rest of the specimen remained intact, strong, and brittle. The cyclic strength of the clay was high in comparison to that required for the foundation of a planned earth dike and was relatively strong in comparison with other clays. However, simplified

● *See **Preface**, page v, for availability of publications marked with dot.*

analyses indicate that under some conditions dynamic loading can be expected to induce instability in this type of soil.

● **5.6-3** Li, J. C., Baladi, G. Y. and Andersland, O. B., **Cyclic triaxial tests on frozen land,** *Engineering Geology,* 13, *1-4,* Apr. 1979, 233–246.

Strain-controlled cyclic triaxial tests were performed on a single-sized silica (Ottawa) sand artificially frozen into 71.1-mm-diameter cylindrical samples. Ice-saturated samples with three different sand contents were tested under the following conditions: axial strains ranging from 3×10^{-3} to 3×10^{-2}%, confining pressures from zero to 1.378 MPa, frequencies of 0.05-5.0 Hz and temperatures from -1 to -10°C. Test equipment included: (1) an MTS electrohydraulic closed-loop testing system which applies the load to the sample; (2) a triaxial cell completely immersed in a low-temperature coolant for temperature control; (3) a refrigeration unit for control of the coolant temperature and constant coolant circulation; and (4) measuring devices including an LVDT and load cell, together with recording devices such as a digital multimeter, an oscilloscope, a strip-chart recorder, and a minicomputer.

Test results indicate that the dynamic Young modulus increases with increasing frequency, confining pressure, and sand content, but that the modulus decreases with increasing strain and temperature. The damping ratio decreases with increasing frequency, sand content, and lower temperatures. The influence of confining pressures and axial strain on the damping ratio are less explicit for the ranges considered. The experimental results are compared with data from other sources.

● **5.6-4** Asama, T. et al., **An experimental study on liquefaction of sandy soils on a cohesive soil layer,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 685–700.

Experimental and theoretical research on liquefaction has resulted in a general understanding that liquefaction occurs when the shear stress reaches a critical value which is determined by such factors as the type of soil, its density, and its normal stress. Previous research shows that an essential factor should be stress levels in the soils. The authors observe, however, that liquefaction chiefly depends upon the strain levels of soils. Especially where a sand layer lies on a soft cohesive soils layer, the strain can be amplified by the response of the cohesive soils.

● **5.6-5** Screwvala, F. N. and Khera, R. P., **Ballistic pendulums and dynamic testing of clays,** *Journal of the Geotechnical Engineering Division, ASCE,* **105**, *GT8,* Aug. 1979, 927–938.

Ballistic pendulums provide simple and effective means of testing clays at a constant rate of strain. Tests were performed at strain rates of 1400%/sec and 2300%/sec. The increasing stiffness of stress-strain response reported for lower strain rates (up to 0.17%/sec) is found to occur for higher strain rates as well as for the horizontally oriented samples. The advantage of ballistic pendulums is further indicated by the fact that, through this method of testing soils, material anisotropy is detectable. The ratio of strengths in the horizontal and vertical directions is found to be a function of consolidation stress.

● **5.6-6** Tatsuoka, F. et al., **Shear modulus and damping by drained tests on clean sand specimens reconstituted by various methods,** *Soils and Foundations,* **19**, *1,* Mar. 1979, 39–54.

Comprehensive tests were performed on a clean sand to evaluate the effects of the methods of sample preparation on shear moduli and hysteretic damping ratios by use of a resonant-column apparatus and a static torsional shear device. All tests were conducted under fully drained conditions. Solid cylindrical specimens were used for resonant-column tests, and hollow cylindrical specimens were used for torsional shear tests. The specimens were sheared torsionally and cyclically. It was found that, for a wide range of shear strains, the shear modulus and the hysteretic damping ratio of the sand tested by cyclic drained shear tests are quite insensitive to the methods of sample preparations adopted. These include the methods of pouring, compaction, moistening, saturation, and nonsaturation.

● **5.6-7** Pyke, R., **Nonlinear soil models for irregular cyclic loadings,** *Journal of the Geotechnical Engineering Division, ASCE,* **105**, *GT6,* June 1979, 715–726.

Current analytical and mechanical models for shear-stress shear-strain relationships under cyclic loading are described. These models generally comply with Masing's suggestion that unloading and reloading curves have the same shape as the initial loading curve except that they are enlarged by a factor of two. A new hypothesis is presented in which this scale factor is made a function of the stress level at the last reversal point. This new hypothesis leads to shear-stress shear-strain relationships under irregular cyclic loading that appears to give better agreement with experimental data than the existing models.

● **5.6-8** Casagrande, A. and Rendon, F., **Gyratory shear apparatus: design, testing procedures, and test results on undrained sand,** *Technical Report S-78-15,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Oct. 1978, 111.

When a saturated mass of undrained sand in situ is subjected to cyclic loading, the stresses within any small element remain uniform although they change cyclically.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

However, in cyclic laboratory tests the stresses on rigid boundaries are nonuniform and the cumulative effect of these stresses during cyclic loading causes progressive redistribution of water content and density within the specimen. The purpose of this investigation was to measure such redistribution in sand subjected to (1) cyclic simple shear (X) tests and (2) gyratory shear (Y) tests, using a gyratory apparatus designed to perform both types of tests. Negator springs mounted on a gyratory arm apply a constant horizontal force which for X tests is transformed into a reciprocating shear force, and for Y tests produces a constant, rotating shear force. The cylindrical test specimen is enclosed in a rubber membrane which is supported on the outside by a flat coil spring whose leaves are slightly separated at the start of the test. At the end of the test the specimen is frozen (permitting expanding water to discharge into a burette) and cut into 64 elements for determination of distribution of water content and relative density.

This report includes (1) a description of apparatus and appurtenant test equipment, with shop drawings, (2) a description of test procedures, (3) typical test results, and (4) discussion. Measured redistribution of density shows clearly that loose and medium dense specimens are compacted in zones adjacent to the rigid top and bottom boundaries and are loosened in zones along the midplane and adjacent to the membrane. With an increasing number of cycles, redistribution and softening in loose and medium-dense specimens continue until steady-state deflections develop. In terms of the relative density of elements, redistribution can be expressed by standard deviation, which is from 2.0 to 2.5 percent for specimens of all densities as placed, and which increases to a maximum of about 10 percent for loose specimens when cycled to steady-state displacements. Significant cyclic softening also develops in dense specimens, although determination of redistribution by freezing and cutting is too crude for measuring magnitude. When steady displacements are reached in X tests, each time the shear stress cycles through zero, the cyclic peak pore pressure increases with a sharp peak almost equal to the effective vertical stress at the start of the test. In Y tests, the pore pressure rises to a maximum that is about two-thirds of the effective vertical stress at the start of the test. When a specimen softens during a cyclic test, the displacements change from a pattern which indicates that the sand responds with a constant shearing resistance to an entirely different pattern with a sudden great drop in shear strength followed by an equally sudden increase. This pattern reflects alternate developments of liquefaction and dilation within one or more zones of a specimen. Urgently needed are more precise measurements of redistribution during the first stage of cyclic tests while cyclic peak pore pressure rises to its maximum. Necessary accuracy could probably be achieved with cyclic triaxial tests and by freezing and cutting specimens into horizontal slices.

● 5.6-9 Silver, M. L., **Cyclic strength of undisturbed sands from Niigata, Japan,** *Technical Report S-78-10,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1978, 174.

Standard penetration tests (SPT), undisturbed field sampling, laboratory index property tests, and laboratory cyclic triaxial strength tests were performed on noncohesive soils from Niigata, Japan, to determine why some soil deposits failed by liquefaction during the 1964 earthquake while apparently similar deposits remained stable. Undisturbed samples for testing were obtained from two relatively nearby sites underlain by essentially the same soil layer: a river site where there was severe surface evidence of liquefaction following the 1964 earthquake and a road site where surface evidence of liquefaction was not observed. Undisturbed soil sampling was performed with a newly designed Japanese large-diameter sampler and with an Osterberg sampler, so that U.S. and Japanese sampling procedures could be compared. Field procedures for obtaining small-diameter specimens from a large-diameter sample were shown to be a successful way to avoid problems in handling samples. This is especially true if field freezing is also used to immobilize the fabric of the soil. It was found that field freezing with liquid nitrogen and storage of the samples in dry ice were convenient ways to transport and store both large and small specimens. In relatively clean, noncohesive soils which are not susceptible to frost heave, such freezing does not seem to significantly alter the soil fabric or sample density.

Comparison of SPT values, index property values, and cyclic triaxial strength values for soils from the two sites prompted the following conclusions. (1) In-situ relative density values were low at both sites ranging between 20% and 60%. The trend was for relative density values to increase with depth. (2) Cyclic triaxial strength values for undisturbed soil specimens were not high. Cyclic stress ratios required to cause failure (defined as 5% double amplitude strain) for 20 stress cycles were on the order of 0.2 for soil specimens at an average relative density of 62% and on the order of 0.14 for soil specimens at an average relative density of 33%. (3) Sampling and testing at the river site showed low SPT values, low calculated relative density values, and low cyclic triaxial strength values. It was concluded that the river site, if unimproved, will show little resistance to liquefaction in future earthquakes. (4) Based on somewhat limited data, it appears that the cyclic triaxial strength of specimens from large-diameter samples and specimens from Osterberg samples are reasonably equivalent when test results were compared at the same value of relative density. (5) SPT values and relative density values were slightly higher for the road site than for the river site but the measured differences were not large. Nevertheless, sand boils, cracking, and other surface indications gave clear evidence that soil at the river site liquefied and soil at the road site did not liquefy during the 1964 earthquake. This difference in behavior may have been caused by higher effective stress at the road site resulting from a lower water table. (6) In reviewing historical records, it appears that most of the severe earthquake damage from liquefaction at Niigata occurred in areas that were reclaimed by dumping sand through water. (7) In performing this study, it became clear that any form of sampling, sample handling, or specimen preparation for relatively clean, noncohesive soils weakens the soil somewhat. Therefore, the test results reported may be considered as a lower bound on expected field behavior of soils from Niigata.

● **5.6-10** Silver, M. L., **Comparison between the strengths of undisturbed and reconstituted sands from Niigata, Japan,** *Technical Report S-78-9, Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station,* Vicksburg, Mississippi, Aug. 1978, 47.

Laboratory cyclic triaxial strength tests were performed on undisturbed and reconstituted sand specimens from Niigata, Japan, to determine how tests on reconstituted specimens can aid in the evaluation of the cyclic strength of in situ noncohesive soils. Undisturbed specimens obtained from careful sampling with a large-diameter sampler appeared to be of high quality; yet cyclic triaxial strengths measured in the laboratory were not particularly high. Specimens failed at cyclic stress ratios of about 0.15 at 20 stress cycles. Reconstituted specimens prepared by pluviating sand through water were weaker than undisturbed specimens by factors of about 1.22 to 1.16. The cyclic strength difference between reconstituted specimens prepared by pluviating sand through water and reconstituted specimens prepared by moist tamping was about the same as the cyclic strength difference between reconstituted specimens prepared by pluviating sand through water and undisturbed field specimens. Thus, sand reconstitution techniques such as wet tamping may be used to better model in situ soil behavior than such reconstitution techniques as pluviation for sands of the type found at Niigata, Japan.

● **5.6-11** Hain, S. J., **Repeated load behaviour of a fine sand,** *UNICIV Report R-187,* Univ. of New South Wales, Kensington, Australia, June 27, 1979, 35.

The prediction of prototype displacement from the results of field model tests requires some knowledge of the relationship between modulus and the confining stress level. In this paper, the triaxial test is used to examine under repeated load conditions the relationship between the secant modulus associated with permanent deformation and the confining stress level. A relationship of the form $E_p \propto \sigma_3^y$ is proposed and the value of y is shown to be dependent on the stress ratio ($R = \sigma_1/\sigma_3$). For $R \leq 2$, values of y less than 0.2 are predicted. This is consistent with an increased influence of grain crushing on the repeated load behavior of the material. As the stress ratio increases, the value of y increases and appears to reach a maximum between 0.5 and 0.7 for the maximum stress ratio considered.

● **5.6-12** Frydman, S. et al., **Aspects of liquefaction study of a cemented sand,** *Faculty Publication 252,* Faculty of Civil Engineering, Technion, Haifa, Israel, May 1979, 42.

This paper describes aspects of a liquefaction investigation of a variably cemented sandy profile. Because of the difficulty involved in extracting undisturbed samples for testing, an evaluation was made of the use of standard penetration test results (i.e., blow counts) and samples in studying such profiles. A method for obtaining intact specimens for laboratory testing by means of block sampling, freezing, and coring was developed; and cyclic triaxial tests performed on specimens obtained in this way provided cyclic strength data relevant for the soils encountered in the profile. These results were compared to those obtained by testing reconstituted specimens and were considered to be more relevant to in-situ conditions.

● **5.6-13** Lu, T. D., Miller, V. G. and Fischer, J. A., **Cyclic pile load testing—loading system and instrumentation,** *Behavior of Deep Foundations,* 435–450. (For a full bibliographic citation, see Abstract No. 1.2-23.)

The scope, concepts, methodology, and details of a load application system and instrumentation for the successful operation of a series of cyclic pile load tests are described. The purposes of the pile tests on an instrumented H-pile were to evaluate the dynamic behavior of piles under cyclic loading conditions for seismic analyses and design of a structure supported on piles. The scope of the pile load tests included a static vertical, cyclic vertical, and cyclic lateral loading, with a sustained constant vertical load. A major requirement of the cycle testing was to apply a controlled varying load intensity to the pile in a specific wave shape at a specific frequency. To fulfill this requirement, an automated closed-loop loading system, which consisted of an electronic-electromechanical control system interfaced with hydraulic loading components, was developed. An instrumentation program was implemented to measure the static and cyclic response of the test pile to include (1) bending moments and axial compression of the pile during driving; (2) loads, moments, angular rotation, and deflections of the pile during testing; and (3) the configuration of pile after driving and after each increment of load application.

● **5.6-14** Lu, T. D., Fischer, J. A. and Miller, V. G., **Static and cyclic axial load tests on a fully instrumented pile,** *Behavior of Deep Foundations,* 416–434. (For a full bibliographic citation, see Abstract No. 1.2-23.)

The results of static and cyclic axial pile load tests performed on a fully instrumented steel H-pile driven into a glacial till deposit are presented. Cyclic loads were applied by means of a hydraulic system interfaced with an automated electronic-electromechanical closed-loop servo-system to achieve a controlled-load intensity of a specific shape (sinusoidal) at a specific frequency (0.1 Hz). The load-deflection, load transfer, and configuration of the pile during pile driving and after each load increment were measured by use of an instrumentation system that consisted of load cells, deflectometers, strain gages, accelerometers, and inclinometers. Data obtained in this investigation indicated that: (1) Axial deformation of the pile remained essentially constant prior to and after cyclic axial load application. The behavior of the pile was essentially elastic during cyclic load application. (2) Within the scope of the testing performed, cyclic vertical load increments do not affect the load-carrying capacity or load transfer characteristics of the pile. (3) Load transfer characteristics varied with the magnitude of the applied axial load. The ratio of point bearing resistance to the applied load increased with the applied load; however, the rate of increase generally decreases with increasing applied load.

● *See **Preface**, page v, for availability of publications marked with dot.*

6. Dynamics of Structures

6.1 General

6.1-1 Karapetyan, B. K. and Karapetyan, N. K., **Seismic response of buildings and structures** (Seismicheskie vozdeistviya na zdaniya i sooruzheniya, in Russian), Nauka, Moscow, 1978, 159.

Research findings on the seismic response of buildings and structures to earthquakes and explosions are studied, in addition to problems of technique and equipment for evaluating the response. Major topics covered include: seismic risk evaluation, seismic and microseismic vibrations and spectra in earthquakes and explosions; intensity of seismic response to strong-motion earthquakes and to violent explosions; modeling of seismic response; interaction of buildings and structures with soils and foundations in a seismic environment; methods for studying and measuring earthquake response; response spectra of buildings and structures with reference to techniques and instrumentation. A capsulized discussion of effects of some recent (1970–1976) destructive earthquakes is appended.

● **6.1-2** Pusey, H. C. et al., **An international survey of shock and vibration technology**, Shock and Vibration Information Center, U.S. Naval Research Lab., Washington, D.C., 1979, 1 vol.

6.2 Dynamic Properties of Materials and Structural Components

● **6.2-1** Imai, H. and Kosugi, K., **Studies on properties of framed shear walls after cracking-proposal on analysis method of indirectly measured values and example of its application** (in Japanese), *Transactions of the Architectural Institute of Japan, 278*, Apr. 1979, 81–90.

This report concerns the properties of framed shear walls after cracking. The results of theoretical analysis obtained by transposing a shear wall to a truss model are compared with test results. A method is shown to analyze the deformation state and stress state of a specimen using directly measured test data. Upon application of this method to the above-mentioned specimen, it is possible to obtain the specimen failure process, the deformation and stress states of the specimen, and the hysteresis curves of various members (stress vs. strain relationship). These results and the results of theoretical analysis are summarized as follows: (1) Wall concrete before cracking approximates a pure shearing stress state. (2) Wall concrete after cracking forms a compressive field and pushes out the peripheral frame to the outside. Wall bars also act as tensile members. For the specimen, the wall of which has a larger ratio of reinforcement, these bars are idealized into members having origin-oriented hysteretic characteristics, with the tensile strength of concrete as a yielding point. (3) For steel-framed shear walls, frame stiffness after wall cracking can be evaluated by the elastic rigidity of steel skeletons. (4) In the peripheral frame of the test body, axial force is predominant but the bending moment is small. When the maximum yield strength is almost reached, the shearing force also becomes considerably larger.

● **6.2-2** Tomii, M. and Ohno, H., **Practical calculation method of the stiffness matrix of framed shear walls (Part I: characteristic of the elements of fundamental flexibility matrix and fundamental stiffness matrix)** (in Japanese with English summary), *Transactions of the Architectural Institute of Japan, 278*, Apr. 1979, 91–102.

● **6.2-3** Tomii, M. and Ohno, H., **Practical calculation method of the stiffness matrix of framed shear walls (Part II: practical calculation method of fundamental flexibility matrix)** (in Japanese with English summary), *Transactions of the Architectural Institute of Japan, 279*, May 1979, 85–96.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **6.2-4** Laura, P. A. A., Grossi, R. O. and Soni, S. R., **Free vibrations of a rectangular plate of variable thickness elastically restrained against rotation along three edges and free on the fourth edge,** *Journal of Sound and Vibration,* **62**, *4*, Feb. 22, 1979, 493-503.

A literature search has shown that the title problem has received no treatment. In this paper, solutions are presented as obtained (1) by use of the Ritz method with deflection functions which are simple polynomials, and (2) by use of the extended Kantorovich method. The natural boundary conditions along the free edge are not satisfied in the first case, while they are complied with approximately when using the second approach. The fundamental frequency coefficient is determined, and good agreement is shown to exist between the results obtained by the two methods.

● **6.2-5** Suzuki, S.-I., **Dynamic behaviour of a beam subjected to a force to time-dependent frequency (effects of solid viscosity and rotatory inertia),** *Journal of Sound and Vibration,* **62**, *2*, Jan. 22, 1979, 157-164.

The dynamic behavior of a beam is investigated when the frequency of external forcing passes through the first critical frequency of the beam, increasing or decreasing. Solid viscosity, through the use of a Voigt-type mechanical model, and rotatory inertia are taken into account. Integrations involved in the theoretical results are carried out by Simpson's rule. From the results of the theoretical analysis, it is evident that the extreme values of the dynamic deflections decrease remarkably after they reach the maximum values, and that the effect of rotatory inertia on the maximum deflections is very small.

● **6.2-6** Saito, H. and Otomi, K., **Vibration and stability of elastically supported beams carrying an attached mass under axial and tangential loads,** *Journal of Sound and Vibration,* **62**, *2*, Jan. 22, 1979, 257-266.

The vibration and stability of an elastically supported beam carrying an attached mass and subjected to axial and tangential compressive loads are investigated. The analysis is based on the Timoshenko beam theory, and the effects of the attached mass are expressed with Dirac delta functions. The influences of the support stiffness, the direction of loading, and the slenderness ratio on the natural frequency and critical load of a beam are discussed.

● **6.2-7** Mizusawa, T., Kajita, T. and Naruoka, M., **Vibration of skew plates by using B-spline functions,** *Journal of Sound and Vibration,* **62**, *2*, Jan. 22, 1979, 301-308.

This paper examines the free vibration of skew plates by the Rayleigh-Ritz method with B-spline functions as coordinate functions. The convergence of the solutions is investigated in a few typical cases and is found to be satisfactory. The accuracy of the results is compared with the existing results based on other numerical methods and is found to be in good agreement.

6.2-8 Desayi, P., Iyengar, K. T. S. R. and Reddy, T. S., **Stress-strain characteristics of reinforcing steel bars under cyclic loading,** *Journal of Testing and Evaluation,* **7**, *4*, July 1979, 199-207.

This paper presents test results for 22 high-strength deformed bars and nine mild steel bars subjected to monotonic repeated and reversed axial loading to determine the stress-strain behavior. Stress-strain curve equations are proposed and compared with test results. Satisfactory agreement is obtained.

6.2-9 Kanatani, K.-I., **A micropolar continuum model for vibrating grid frameworks,** *International Journal of Engineering Science,* **17**, *4*, 1979, 409-418.

A principle for converting a discrete system of grid frameworks into an equivalent micropolar continuum model is given with the degree of approximation taken into consideration. A micropolar continuum is defined in the form of higher order extension. In order to correct the defects of previous theories, a complex-valued micropolar continuum model is constructed for grid frameworks vibrating with an arbitrary frequency. The variational principle related to the average energy of the system is used to construct the model. A wave propagation analysis reveals the existence of high-frequency waves. The accuracy of solutions is also investigated.

● **6.2-10** Tonin, R. F. and Bies, D. A., **Free vibration of circular cylinders of variable thickness,** *Journal of Sound and Vibration,* **62**, *2*, Jan. 22, 1979, 165-180.

Flexural vibrations of finite length circular cylinders with shear diaphragm ends and symmetric circumferential wall thickness variations are described using the Rayleigh-Ritz method. Both symmetric and asymmetric solutions are presented. Only circumferential variations in the wall radial dimension are considered; the method is amenable, however, to consideration of longitudinal variations in wall thickness as well. The cylinder wall thickness variation is described as a Fourier series, and the vibration is described as a series of modes of a uniform cylinder with the same mean radius. The theory is applied to a cylinder whose inner bore is circular but is nonconcentric with the circular outer surface. The mode shapes were investigated experimentally by using time-averaged holograms of the vibrating cylinder, and the results compare well with the predictions of the theory. The frequencies of the modes agree with the theoretical predictions to within 2%.

● **6.2-11** Teh, K. K. and Huang, C. C., **The vibrations of generally orthotropic beams, a finite element approach,**

● *See **Preface**, page v, for availability of publications marked with dot.*

Journal of Sound and Vibration, **62**, *2*, Jan. 22, 1979, 195–206.

This paper presents two finite element models for the prediction of free vibrational natural frequencies of generally orthotropic fixed-free beams. The discrete models include the transverse shear deformation effect and the rotary inertia effect. Numerical studies show that the convergence rate of the approximations calculated from the finite element analysis is dependent on the fiber orientation.

6.2-12 Markus, S., **Refined theory of damped axisymmetric vibrations of doubled-layered cylindrical shells,** *The Journal of Mechanical Engineering Science*, **21**, *1*, Feb. 1979, 33–37.

The governing differential equations of vibrations of double-layered cylindrical shells are derived from classical thin-shell theory. The outer layers of the shells are assumed to be viscoelastic and to possess a high damping capacity to control vibrations. Decoupled torsional and coupled radial-longitudinal vibration modes are analyzed by means of the damped normal mode method. The present theory refines Kagawa and Krokstad's analysis. The results obtained point to a strong dependence of mechanical losses upon the thickness-to-radius ratio, h_1/R, even for axisymmetric modes. This phenomenon was not recognized in the Kagawa-Krokstad approach.

● **6.2-13** Olson, M. D. and Hazell, C. R., **Vibrations of a square plate with parabolically varying thickness,** *Journal of Sound and Vibration*, **62**, *3*, Feb. 8, 1979, 399–410.

Vibration results for a square plate with a parabolically varying thickness distribution and built-in edges are presented. Frequency and mode shape predictions obtained from a finite element analysis are compared with measurements made with real-time laser holography. In general, the agreement between the two is very good except for a few of the lower modes where the predicted frequencies are about 15% high. A satisfactory explanation for this has not been found. The vibration mode shapes for the plate exhibit a striking blend of radial and square symmetries that result from the axisymmetric thickness distribution and the square symmetry of the boundary frame.

● **6.2-14** Huang, C. L. and Aurora, P. R., **Non-linear oscillations of elastic orthotropic annular plates of variable thickness,** *Journal of Sound and Vibration*, **62**, *3*, Feb. 8, 1979, 443–453.

A computational analysis of the nonlinear oscillations of elastic orthotropic annular plates of variable thickness is presented. The nonlinear boundary value problem is converted into a corresponding eigenvalue problem by using a Kantorovich time-averaging method. Then, by means of a Newton-Raphson iteration scheme in conjunction with the concept of analytical continuation, the solutions to the nonlinear oscillations of elastic orthotropic annular plates of variable thickness are obtained.

● **6.2-15** Guruswamy, P. and Yang, T. Y., **A sector finite element for dynamic analysis of thick plates,** *Journal of Sound and Vibration*, **62**, *4*, Feb. 22, 1979, 505–516.

A 24 degree-of-freedom sector finite element is developed for the static and dynamic analysis of thick circular plates. The element formulation is based on Reissner's thick plate theory. The convergence characteristic of the elements is first studied in a static example of an unsymmetrically loaded annular plate. The obvious advantageous effect of including the twist derivatives of deflection as degrees-of-freedom is shown. The elements are then used to analyze the natural frequencies of an annular plate with various ratios of inner to outer radius. The results are in good agreement with an alternative solution in which thick plate theory is used. The versatility of this finite element is demonstrated by performing free vibration analysis of an example of clamped sector plates with various thicknesses and different sectorial angles.

● **6.2-16** Wilson, Jr., H. B. and Farrior, D. S., **Stress analysis of variable cross-section indeterminate beams using repeated integration,** *International Journal for Numerical Methods in Engineering*, **14**, *6*, 1979, 855–870.

A simple computer method is presented for analyzing statically indeterminate beams having sectionally constant *EI* values and loads consisting of any number of arbitrarily placed concentrated forces and couples as well as any number of uniform and ramp loads. Unknown reactions are treated as parameters which are determined by simultaneous imposition of end conditions and interior constraints. Support locations are specified independently of any discontinuities of load or cross section. A computer program implementing this method is described which has more concise data input than is typically required in programs based on the stiffness method.

● **6.2-17** Crespo da Silva, M. R. M. and Glynn, C. C., **Nonlinear non-planar resonant oscillations in fixed-free beams with support asymmetry,** *International Journal of Solids and Structures*, **15**, *3*, 1979, 209–219.

The order-three, integro differential, nonlinear equations of motion for an inextensional beam, derived by the authors in a previous publication, are analyzed to investigate nonlinear resonant coupling effects between the nonplanar free oscillation modes of a fixed-free beam with asymmetric support conditions. The transition curves that separate nonlinear resonant and nonresonant types of motions for the beam, and the main characteristics of the nonlinear motions are determined analytically.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **6.2-18** Venkataramana, J., Maiti, M. and Srinivasan, R. K., **Vibration of rectangular plates with time-dependent boundary conditions,** *Journal of Sound and Vibration,* **62,** *3,* Feb. 8, 1979, 327–337.

A general method of solution for the vibration of rectangular plates with any type of time-dependent boundary conditions is developed by an extension of the Mindlin and Goodman method. For illustration, the problems of a plate with different time-dependent boundary conditions are solved, and the closed-form solutions for the transverse deflections of the plate are obtained. The nondimensionalized transverse deflections, (w/a) at the middle of the plate, are evaluated numerically for different dimensions of the plate and different forcing functions. These are presented graphically against the nondimensionalized time, T, for three cases and tabulated for other cases.

● **6.2-19** Symonds, P. S. and Wierzbicki, T., **Membrane mode solutions for impulsively loaded circular plates,** *Journal of Applied Mechanics, ASME,* **46,** *1,* Mar. 1979, 58–64.

Large deflections of a clamped circular plate subjected to axially symmetric impulsive loading are obtained by means of the mode approximation technique. The mode shapes and accelerations are determined by equations assuming simple membrane action. The predicted deflections and response times are compared with quantities measured in recently published experiments on plates of steel, titanium, and lead. In view of the extreme simplicity of the approximate method, the good agreement at large deflections, observed in the case of the two structural metals, is of practical interest.

● **6.2-20** Ha, H. K. and Hassan, F., **Seismic response of multistory frames clad with corrugated panels,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 847–872.

Cold-formed corrugated steel panels are effective for controlling the drift of multistory frames, provided that the cladding is properly connected to the bare frame. This paper presents a method of analysis of the cladding itself and of the integrated frame. The cladding stiffness matrix is derived taking into account the flexibility of the connections, shear strains in the sheeting, bending of the corrugation profile, and axial strains in the perimeter members. Analyses of two welded shear diaphragms yield results comparable to those of finite element analyses and tests.

The conventional direct stiffness technique is then used to evaluate the seismic response of two clad frames having 26 and 40 stories with 3 bays. The results obtained are described in a general manner so as to be applicable to other similar frames. The use of cladding does reduce the lateral deflections but may increase the member forces, especially the axial forces in the adjacent columns. It is recommended that overstiff cladding be avoided until further studies of the energy dissipation capacity and overall ductility of cladding indicate otherwise.

● **6.2-21** Dyka, C. T. and Carney III, J. F., **Vibrations of annular plates of variable thickness,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM3,* Proc. Paper 14638, June 1979, 361–370.

An exact solution for the circular frequencies of a polar orthotropic annular plate of uniform and parabolic thickness under the action of in-plane forces is presented. The annular plate is reinforced with simply supported edge beams at both the inner and outer boundaries. The edge beams are subjected to uniform, radial compressive loadings. Frequency parameters, determined for both axisymmetric and higher modes, are found to be functions of the in-plane loads, plate dimensions and rigidities, edge-beam stiffness and moment-of-inertia parameters, and the profile of the plate. The use of edge beams provides a practical method of simulating various types of edge conditions for the polar orthotropic annular plate, including the limiting cases of simply supported and clamped edges.

● **6.2-22** Warburton, G. B., **Response using the Rayleigh-Ritz method,** *Earthquake Engineering & Structural Dynamics,* **7,** *4,* July–Aug. 1979, 327–334.

As an example of the extension of the Rayleigh-Ritz method to response calculations, an analysis is outlined for a damped rectangular plate. For harmonic excitation, amplitudes of displacement and bending moment are compared with values from a modal solution of the plate equation. In general, the Rayleigh-Ritz method predicts displacements of acceptable accuracy, but for a given number of terms accuracy is less for response calculations than for the determination of comparable eigenvalues. Bending moments may converge slowly to the true values, as the number of terms in the assumed series is increased.

● **6.2-23** Beltzer, A. I., **The influence of porosity on vibrations of elastic solids,** *Journal of Sound and Vibration,* **63,** *4,* Apr. 22, 1979, 491–498.

Wave scattering resulting from inhomogeneities in a solid leads to damping of wave motion in a random mixture of elastic materials. This phenomenon is observed particularly in a material containing random porosity. A general dissipative model is presented to evaluate the influence of small randomly distributed pores on the dynamic response of elastic structures. The numerical results are given for transverse wave propagation and for vibrations of a beam. It is shown that analysis of vibrations of elastic solids containing random porosity can be carried out by the methods of viscoelasticity.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

● **6.2-24** Bapat, V. A. and Kumaraswamy, H. V., **Effect of primary system damping on the optimum design of an untuned viscous dynamic vibration absorber,** *Journal of Sound and Vibration,* **63,** *4,* Apr. 22, 1979, 469–474.

Explicit criteria for the optimum design of an untuned viscous dynamic vibration absorber are developed for the case of a viscously damped single degree-of-freedom spring-mass system. It is shown that, for the particular case of an undamped main system, the results reduce to the classical ones obtained by using the concept of a fixed point on the response curve.

● **6.2-25** Ozdemir, H., **A finite element approach for cable problems,** *International Journal of Solids and Structures,* **15,** *5,* 1979, 427–437.

A finite element approach is proposed for the static and dynamic nonlinear analysis of cable structures. Starting from the stress equations of equilibrium, the author derives a variational formulation in which the static and kinematic variables are measured in some previous configuration of the body. To discretize this variational form of equilibrium equations, Lagrangian functions are employed to interpolate the curved geometry of each element, and only displacement continuity is enforced between element nodes. By introducing a separate interpolation for arc length, displacement patterns which leave element nodal arc lengths constant are not allowed to induce strains in the element. The finite element matrices resulting from the operations of linearization and discretization are derived. By evaluating the stiffness matrix of the two-node element, it is shown explicitly that the element stiffness matrix is independent of whether the initial configuration or the current configuration is used in the description of kinematic and static variables. Sample analyses are presented to demonstrate the utility and reliability of the proposed elements.

● **6.2-26** McNiven, H. D. and Mengi, Y., **A mathematical model for the linear dynamic behavior of two phase periodic materials,** *International Journal of Solids and Structures,* **15,** *4,* 1979, 271–280.

In this study, a mathematical model is developed for two-phase materials with the object of using the model for predicting the response of masonry walls to dynamic inputs. The method employed here uses the theory of mixtures applied to a two-phase material in which the phases reflect a periodic structure and in which each phase is linearly elastic. Employing the fundamental equations of the theory of mixtures, the authors establish the governing equations of a linear approximate theory. The theory, valid for an arbitrary direction of motion, replaces the composite by a homogeneous, two-phase, anisotropic, elastic solid. The theory accommodates the dispersive nature of the composite by means of an elastodynamic operator, which is introduced into the constitutive relations of the linear momentum interactions. Parts 2 and 3 of this three-part study are described in Abstract Nos. 6.2–27 and 6.2–28.

● **6.2-27** McNiven, H. D. and Mengi, Y., **A mixture theory of elastic laminated composites,** *International Journal of Solids and Structures,* **15,** *4,* 1979, 281–302.

A theory is developed which governs the dynamic response of a homogeneous, elastic, dispersive material. The material is used as a model of a two-phase layered material in which each of the layers is isotropically elastic. The theory is derived from a general theory for all two-phase periodic materials which was developed earlier in Part 1 (see Abstract No. 6.2-26). The general theory was derived using the theory of mixtures. Dispersion is accommodated through the use of elastodynamic operators, and, for the layered material, a micro-model is used to establish the forms of the operators appropriate to the material. These specific operators are simplified by replacing them with a truncated power series before introducing them into the equations of linear momentum. The theory for layered materials contains 19 model constants, and equations are developed from which these constants can be derived from the layer constants. The equations are partly derived using micro-model analysis and partly by matching specific dynamic behaviors of the model and prototype. The ability with which the model predicts the dynamic response of the layered material is assessed in two ways. Both ways compare spectra reflecting the behavior of infinite trains of the principal kinds of waves. The first compares spectral lines from the model with those derived from the exact theory for layered materials. The second compares lines from the model with those obtained from experiments. Predictions from the model prove to be accurate. Part 3 of this three-part study is described in Abstract No. 6.2–28).

● **6.2-28** McNiven, H. D. and Mengi, Y., **Propagation of transient waves in elastic laminated composites,** *International Journal of Solids and Structures,* **15,** *4,* 1979, 303–318.

This paper concerns the appraisal of a model material which can be used to replace a material constructed of alternate plane layers. The material is homogeneous, anisotropically elastic and dispersive. The purpose of the model is to study the dynamic response of masonry walls. The equations governing the model consist of constitutive equations and equations of linear momentum. The theory is constructed using the theory of mixtures, and dispersion is accommodated by means of elastodynamic operators introduced into the equations of linear momentum. The theory contains 19 constants. The derivation of the governing equations and equations relating the model constants to those of the prototype are presented in earlier papers (see Abstract Nos. 6.2–26 and 6.2–27).

● *See **Preface**, page v, for availability of publications marked with dot.*

In this paper, the model is appraised by comparing the responses predicted by the model for a transient input with those observed experimentally. Experimental data allow comparison of the behavior of dilatational waves traveling parallel and perpendicular to the layers in plates and semi-infinite bodies. Where possible, comparison is also made with responses predicted by the exact theory. Responses in the model are found using the method of characteristics. Comparison is exhibited in a number of figures and shows that the responses predicted by the theory are accurate. The accuracy is not restricted to early arrival times but extends to behavior far behind the head of the pulse.

● 6.2-29 Chan, H. C. and Foo, O., **Vibration of rectangular plates subjected to in-plane forces by the finite strip method,** *Journal of Sound and Vibration,* **64**, *4*, June 22, 1979, 583-588.

The finite strip method is applied to the vibration analysis of rectangular plates subjected to in-plane forces. Several numerical examples are presented, and comparison with available solutions indicates the accuracy and efficiency of the method.

● 6.2-30 Kunukkasseril, V. X. and Venkatesan, S., **Axisymmetric non-linear oscillations of isotropic layered circular plates,** *Journal of Sound and Vibration,* **64**, *2*, May 22, 1979, 295-302.

Nonlinear equations of motion for isotropic layered circular plates are presented for axisymmetric motion. Further simplification is made by ignoring the in-plane and rotatory inertia terms. Explicit solutions are obtained for the forced and free oscillations. In this case, it is found that the nonlinearity is of the hardening type. Numerical results are presented for the case of a two-layered plate of aluminum and steel.

● 6.2-31 Laura, P. A. A. and Grossi, R. O., **Transverse vibrations of rectangular anisotropic plates with edges elastically restrained against rotation,** *Journal of Sound and Vibration,* **64**, *2*, May 22, 1979, 257-267.

This paper presents an approximate solution of the title problem by use of very simple coordinate functions, which partially satisfy the boundary conditions, and the Ritz method. Values of the fundamental frequency coefficient and the value corresponding to the first fully antisymmetric mode are determined as a function of the edge spring coefficients.

● 6.2-32 Thambiratnam, D. P., Shah, A. H. and Cohen, H., **Axisymmetric transients in shells of revolution,** *Earthquake Engineering & Structural Dynamics,* **7**, *4*, July-Aug. 1979, 369-382.

The propagation of axisymmetric transients in shells of revolution subjected to impulsive boundary loads is treated in this paper. Consideration is restricted to linear, elastic, isotropic, homogeneous shells of revolution with straight line generators. The analysis is based on the concept of a wave as a carrier of discontinuities in the field variable and its derivatives. These discontinuities are determined from a set of recurrence relations which are in turn generated by the use of asymptotic series solutions to the equations of motion. A numerical superposition technique which enables the calculation of a long time response is developed. Several numerical examples illustrate the method.

● 6.2-33 Mirza, S. and Singh, A. V., **Axisymmetric vibration of continuous shallow spherical shells,** *Journal of Sound and Vibration,* **62**, *1*, Jan. 8, 1979, 65-72.

The axisymmetric vibration of shallow shells supported along the outer periphery $r = a$ and along an intermediate circle of radius $r = b$ is considered. Shear deformation effects are included in the differential equations. This makes the analysis of higher modes more meaningful. Results are presented for three cases: (1) the fixed edge condition at $r = a$; (2) the simply supported condition at $r = a$; (3) the free edge condition at $r = a$.

● 6.2-34 Goodno, B. J., **Glass curtain wall elements: properties and behavior,** *Journal of the Structural Division, ASCE,* **105**, *ST6*, Proc. Paper 14656, June 1979, 1121-1136.

Recent failures of glass claddings in modern highrise buildings have called attention to the need for improved understanding of the static and dynamic behavior of cladding so that rational procedures for its design can be developed. A frame-panel finite element model was developed to represent a typical portion of the glass curtain wall between story levels in a 29-story glass-clad building and a parametric study of its displacement response and vibration properties was conducted. Window response is shown to be sensitive to the rotational stiffness of the gasket and flexural stiffness of the framing elements for selected panel aspect ratios. Vibration frequencies of the frame-window system are in good agreement with values obtained in field and laboratory experiments. The cladding model presented is suitable for inclusion in existing multistory building models and is currently being used to study cladding-structure interaction in highrise buildings.

● 6.2-35 Monforton, G. R., **Stiffness matrix for sandwich beams with thick anisotropic laminated faces,** *Computers & Structures,* **10**, *3*, June 1979, 547-551.

A finite element capability is described for the analysis of sandwich beams with thick unbalanced laminated faces. Particular attention is focused on the effects of bending-membrane coupling in the faces. The stiffness matrix is

● See *Preface*, page v, for availability of publications marked with dot.

developed using displacement functions generated from explicit solution of the governing differential equations.

● 6.2-36 Sheinman, I., **Forced vibration of a curved beam with viscous damping,** *Computers & Structures,* **10,** *3,* June 1979, 499–503.

A generalization of the dynamic solution for an arbitrary plane curved beam with viscous damping, under arbitrary load, is presented. The equation of motion, based on the linear theory, admits proportionality of the damping to the mass and stiffness matrices (Rayleigh damping). The numerical solution is obtained by direct time-integration, using Houbolt's backward differences method. A general computer program (CURBEAM) was written for this purpose and a numerical example is presented.

● 6.2-37 Hinton, E. and Bicanic, N., **A comparison of Lagrangian and serendipity Mindlin plate elements for free vibration analysis,** *Computers & Structures,* **10,** *3,* June 1979, 483–493.

The performance is evaluated of five Lagrangian and serendipity (4-, 8-, 9-, 12-, and 16-noded) isoparametric finite elements in the free vibration analysis of Mindlin plates. The results are compared with well-established analytical and numerical solutions based on Mindlin's thick plate theory and three-dimensional elasticity solutions.

● 6.2-38 Mei, C., Narayanaswami, R. and Rao, G. V., **Large amplitude free flexural vibrations of thin plates of arbitrary shape,** *Computers & Structures,* **10,** *4,* Aug. 1979, 675–681.

A finite element formulation is developed for analyzing large amplitude free flexural vibrations of elastic plates of arbitrary shape. Stress distributions in the plates, deflection shape, and nonlinear frequencies are determined from the analysis. Linearized stiffness equations of motion governing large amplitude oscillations of plates, the quasi-linear geometrical stiffness matrix, solution procedures, and convergence characteristics are presented. The linearized geometrical stiffness matrix for an 18 degree-of-freedom conforming triangular plate element is evaluated by using a seven-point numerical integration. Nonlinear frequencies for square, rectangular, circular, rhombic, and isosceles triangular plates, with edges simply supported or clamped, are obtained and compared with available approximate continuum solutions. The comparisons demonstrate that the present formulation gives results entirely adequate for many engineering purposes.

6.2-39 Nagaya, K., **Vibrations of a plate with an elastic constraint of eccentric circular part,** *The Journal of the Acoustical Society of America,* **66,** *1,* July 1979, 185–191.

In this paper, a method for solving vibration problems of a viscoelastic plate having an eccentric circular constraint is presented. The frequency equation in a complex form for the plate with arbitrary shape is obtained. Numerical calculations are carried out for two cases of a circular plate with an eccentric circular stepped surface and a circular plate on an eccentric elastic foundation. The nondimensional natural frequencies and the logarithmic decrements are given for these plates.

6.2-40 Leissa, A. W., Laura, P. A. A. and Gutierrez, R. H., **Transverse vibrations of circular plates having nonuniform edge constraints,** *The Journal of the Acoustical Society of America,* **66,** *1,* July 1979, 180–184.

The free vibrations of circular plates having flexible edge supports have been studied by several researchers for the restricted case when the supports are represented by springs having constant stiffness. In this paper, a general method is presented for dealing with supports having translational and rotational flexibilities which vary in an arbitrary manner around the boundary. It is shown that the varying stiffnesses can be represented as accurately as desired by expanding them into trigonometric series in the polar angle. The exact solution in polar coordinates of the differential equation of motion for the plate is then substituted into the elastic boundary conditions. The resulting infinite characteristic determinant is solved by successive truncation. As an example, the case of a plate having a simply supported edge (infinite translational stiffness) with rotational stiffness varying according to $L_0 + L_1 \cos\theta$ (L_0 and L_1 being constants) is considered. Numerical results are obtained by the method described above and also by using the Ritz method with functions which approximate the differential equation and the boundary conditions.

6.2-41 Dikmen, M., **Some recent advances in the dynamics of thin elastic shells,** *International Journal of Engineering Science,* 17, *6,* 1979, 659–680.

Asymptotic methods make it possible to consistently simplify the governing differential equations, depending on the dominant character of the vibrations. The results obtained for quasi-transverse vibrations can be used in discussing the edge effect, the nodal line density, and the spectral properties. Caustics can be investigated by introducing an Airy function representation. A perturbation procedure makes it possible to approach the inverse problem of vibration.

6.2-42 Caputo, M., **A model for the fatigue in elastic materials with frequency independent *Q*,** *The Journal of the Acoustical Society of America,* **66,** *1,* July 1979, 176–179.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

The phenomenon of fatigue in elastic materials is represented by introducing a derivative of real order in the stress-strain relation. This model also allows estimation of the number of cycles which would give fatigue as a function of the maximum strain applied and of its frequency.

6.2-43 Greenberg, J. B. and Stavsky, Y., **Flexural vibrations of certain full and annular composite orthotropic plates,** *The Journal of the Acoustical Society of America,* **66,** *2,* Aug. 1979, 501-508.

The uncoupled equation of motion is presented for the flexural displacement of an orthotropic composite circular plate having symmetric lamination. A numerical method is employed to calculate the symmetric and nonsymmetric vibrational frequencies of full and annular composite plates subjected to a variety of boundary conditions. Effects produced by lamination interchange and fiber reversal are discussed. In particular, certain laminations are capable of producing a higher fundamental frequency than either of the constituent materials alone can attain. For annular plates, it is found that, for certain lay-ups, the fundamental frequency derives from a nonsymmetric mode. Finally, pinhole-center annuli are examined, and, for a free inner edge, a comparison is made with corresponding full-plate frequencies.

● 6.2-44 Geschwindner, Jr., L. F. and West, H. H., **Parametric investigations of vibrating cable networks,** *Journal of the Structural Division, ASCE,* **105,** *ST3,* Proc. Paper 14436, Mar. 1979, 465-479.

Natural frequencies and modes of vibration are determined for hyperbolic paraboloid cable networks composed of a linkage of straight members connected by frictionless pins with concentrated masses lumped at the connection points. The frequencies and mode shapes are determined through a QL transformation procedure using the linear equations of motion. A numerical problem is examined, and the natural frequencies are presented. Six parameter studies are conducted to determine how the natural frequencies and mode shapes are altered in response to variations in scale factor, mass, applied force, modulus of elasticity, prestress, and sag.

● 6.2-45 Babu, P. V. T., Reddy, D. V. and Sodhi, D. S., **Frequency analysis of thick orthotropic plates on elastic foundation using a high precision triangular plate bending element,** *International Journal for Numerical Methods in Engineering,* **14,** *4,* 1979, 531-544.

A high-precision, triangular, thick orthotropic plate-bending element on an elastic foundation is developed for the free vibration analysis of thick plates on elastic foundations. The element has three nodes with 12 degrees-of-freedom per node and takes into account shear deformation and rotatory inertia. The accuracy of the element is established by comparison with available results of the natural frequencies of thick and thin plates, determined from a consistent mass matrix formulation.

● 6.2-46 Knapp, R. H., **Derivation of a new stiffness matrix for helically armoured cables considering tension and torsion,** *International Journal for Numerical Methods in Engineering,* **14,** *4,* 1979, 515-529.

A new element stiffness matrix is derived for straight cable elements subjected to tension and torsion. The cross section of a cable, which may consist of many different structural components, is treated in this paper as a single composite element. The derivation is quite general; consequently, the results can be used for a broad category of cable configurations. Individual helical armoring wires, for instance, may have unique geometric and material properties. In addition, no limit is placed on the number of wire layers. Furthermore, compressibility of the central core element can also be considered. The equations of equilibrium are first derived to include "internal" geometric nonlinearities produced by large deformations (axial elongation and rotation) of a straight cable element. These equations are then linearized in a consistent manner to give a linear stiffness matrix. Linear elasticity is assumed throughout. Excellent agreement with experimental results for two different cables validates the correctness of the analysis.

● 6.2-47 Gambhir, M. L. and Batchelor, B. deV., **Finite element study of the free vibration of 3-D cable networks,** *International Journal of Solids and Structures,* **15,** *2,* 1979, 127-136.

This paper briefly describes a finite element model previously developed for studying the free vibration characteristics of a single sagged cable hanging freely from two supports. This element, which allows elastic deformations, is used to determine the natural frequencies and normal modes of vibration of 3-D cable networks. A parametric study is made to predict the influence of various parameters, such as the rise-span ratio of cables, initial pretension, cable rigidity, linear dimensions, and surface curvature, on the natural frequencies and normal modes of vibration of 3-D cable networks. The results for various configurations are presented in the form of nondimensional plots.

● 6.2-48 Soni, S. R., **Vibration of beams made of variable thickness layers,** *Journal of Sound and Vibration,* **65,** *1,* July 8, 1979, 75-84.

The free transverse vibrations of a beam composed of variable thickness layers are studied on the basis of Timoshenko shear theory. The differential equations governing the transverse motion of the beam are solved to determine the

● *See **Preface**, page v, for availability of publications marked with dot.*

frequencies by using the quintic spline collocation technique. Frequencies and mode shapes for the first three modes of vibration are computed for various layer thicknesses of clamped and cantilever beams. For comparison, results also are obtained by the finite element method. Both sets of results show a very good agreement. The results for the frequencies are presented in tables, and those for the displacements are given in figures. The effect of layer taper variation on the parameters of interest is studied in detail for beams with three layers.

● **6.2-49** Suzuki, S.-I., **Axisymmetric vibrations of reinforced annular circular plates under impulsive loads,** *Journal of Sound and Vibration,* **65,** *1,* July 8, 1979, 51-60.

The dynamic behavior of an annular circular plate with a reinforced inner edge is investigated for the case in which the plate is subjected to a step impulsive load either radially or transversely. The reinforcing ring is assumed to be a concentrated mass, and the fundamental equations of motion of the plate are solved by the Laplace transformation method. The relationships between the dimensions of the plate and ring, and the maximum values of stresses and bending moments at the inner edge, are obtained. The errors induced by the assumption are also studied by comparing the results with the plane stress solutions.

● **6.2-50** Gill, P. A. T. and Ucmaklioglu, M., **Isoparametric finite elements for free vibration analysis of shell segments and non-axisymmetric shells,** *Journal of Sound and Vibration,* **65,** *2,* July 22, 1979, 259-273.

The eight-node isoparametric shell element with a reduced number of integration points was reported earlier to be incapable of capturing rapid local changes in curvature. In the study reported in this paper, eight- and ten-mode elements are employed to represent shells having geometries with sharp curvatures or with sharp corner connections. The effect of different numbers of integration points on the performances of these elements is surveyed. The information obtained from this survey is used to predict the natural frequencies of an oval cross section hollow shell.

● **6.2-51** Wang, J. T. S., Armstrong, J. H. and Ho, D. V., **Axisymmetric vibration of prestressed non-uniform cantilever cylindrical shells,** *Journal of Sound and Vibration,* **64,** *4,* June 22, 1979, 529-538.

The extended Galerkin method is used in the investigation of axially loaded clamped-free homogenous, isotropic, and elastic cylindrical shells. Both mass and stiffness are considered to vary along the longitudinal direction. The use of Legendre polynomials as shape functions leads to a simple and systematic procedure for determining the natural frequencies and mode shapes. Some numerical results are presented.

● **6.2-52** Sakata, T. and Sakata, Y., **Forced vibrations of a non-uniform thickness rectangular plate with two free sides,** *Journal of Sound and Vibration,* **64,** *4,* June 22, 1979, 573-581.

A forced vibration of a rectangular plate with thickness varying linearly in one direction is studied. The plate is simply supported along two opposite sides and is free along the other sides. Approximate formulas are proposed for estimating the maximum deflection and surface stresses of a rectangular plate subjected to a uniformly distributed harmonic lateral load. The accuracy of the formulas is discussed. The formulas show the possibility of obtaining solutions for the forced vibration of a plate with nonuniform thickness from the solutions for the static bending of the same plate when the plate is subjected to a uniformly distributed load.

● **6.2-53** Bhandari, N. C., Juneja, B. L. and Pujara, K. K., **Free vibration and transient forced response of integrally stiffened skew plates on irregularly spaced elastic supports,** *Journal of Sound and Vibration,* **64,** *4,* June 22, 1979, 475-495.

This paper considers the vibration of integrally stiffened skew plates on irregularly spaced elastic supports. An approximate analysis to obtain the natural frequencies and mode shapes for different edge conditions is presented. Lagrangian equations are used in the analysis. The responses to an exponentially decaying impact load and a half sine wave transient load of a supported skew plate have been determined by modal analysis, with use of the frequencies and the normalized mode shapes thus obtained. The results obtained by this method for the special case of a continuous rectangular plate and for a rectangular, integrally stiffened plate show good agreement with results previously published by other authors.

● **6.2-54** Basci, M. I. et al., **Improved method of free vibration analysis of frame structures,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 255-265. (For a full bibliographic citation, see Abstract No. 1.2-4.)

The objective of this paper is to develop more accurate procedures for the generation of consistent mass matrices of structural elements which can then be embedded in a usual finite element program. This accuracy is achieved by the use of exact rather than approximate displacement functions for the elements. These exact displacement functions are obtained from the solution of the differential equations governing the free vibration behavior of structural components. Two types of elements are considered, straight beam and curved (circular arc) beam elements, both of which have a uniform cross section. However, the general concepts developed in this study are equally applicable to other types of elements, such as plate elements. Obviously, when several types of elements are

● *See* ***Preface****, page v, for availability of publications marked with dot.*

used to model a structure, care must be exercised in enforcing compatibility between two different classes of elements. This procedure has been implemented in connection with planar straight beam elements permitting the generation of the consistent mass matrix of the element. This matrix is obtained in an explicit form which results in improved computational efficiency. The generation of the mass matrix for the curved beam element is in progress. Based on the improved inertial properties and discrete element techniques, a computer program has been developed for the free vibration analysis of frame-type structures. Results have been obtained for various types of structures, including free-free, clamped-free (cantilever) and continuous beams, and simple portal frames. Comparison with exact solutions in these cases indicates that with a relatively small number of elements high accuracy can be achieved in computing the natural frequencies and modes of vibration of these systems. In addition, contrary to other approximate methods such as the Rayleigh-Ritz method, the present procedure yields very good approximations to higher frequencies.

● **6.2-55** Niordson, F. I., **An asymptotic theory for vibrating plates,** *International Journal of Solids and Structures,* **15**, *2*, 1979, 167–181.

The two-dimensional equations of motion for a vibrating plate are derived by means of an asymptotic expansion of the three-dimensional elastic state. The assumptions involved are of mathematical character only and concern the continuity, differentiability, and convergence of the series used. The three-dimensional problem is reduced to a two-dimensional eigenvalue problem consisting of a linear fourth-order partial differential equation for the deflection of the middle-surface and a proper set of boundary conditions. The eigenvalue appears in the coefficients of the differential equation as well as in the boundary conditions. The solution of this problem is discussed and the frequency of stationary plane waves in an infinite plate are computed as an example. The result is compared with the exact solution.

● **6.2-56** Banerjee, M. M., **On the vibration of skew plates of variable thickness,** *Journal of Sound and Vibration,* **63**, *3*, Apr. 8, 1979, 377–383.

This paper is concerned with the determination of the natural frequencies of a vibrating skew plate with variable thickness. Free and forced vibrations are treated for different ratios of the sides, skew angle, and taper constant. The static deflection is also obtained as a by-product of the present solution.

● **6.2-57** Laura, P. A. A., Grossi, R. O. and Carneiro, G. I., **Transverse vibrations of rectangular plates with thickness varying in two directions and with edges elastically restrained against rotation,** *Journal of Sound and Vibration,* **63**, *4*, Apr. 22, 1979, 499–505.

The title problem is solved for the case of linear variation of the thickness in the x- and y- directions using a simple polynomial coordinate function. An approximate but quite convenient frequency equation is derived using the Rayleigh method. Apparently, the available technical literature does not contain a previous analytical treatment of this problem which is as general and simple as the treatment presented in this paper.

● **6.2-58** Fardis, M. N. and Buyukozturk, O., **Shear transfer model for reinforced concrete,** *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM2*, Proc. Paper 14507, Apr. 1979, 255–275.

A functional model is constructed for the shear stiffness of cracks in reinforced concrete under monotonic and cyclic loading. The model, which is in satisfactory qualitative agreement with available experimental results, incorporates more parameters than considered in tests in the past. Supplemented by test results and by a statistical analysis, the functional model is turned into a simple predictive monotonic model that can be used for refined finite element analysis and for establishing a basis for improved design methods for reinforced concrete.

● **6.2-59** Schlesinger, A., **Vibration isolation in the presence of coulomb friction,** *Journal of Sound and Vibration,* **63**, *2*, Mar. 22, 1979, 213–224.

Transmissibility curves for a coulomb-damped flexible mounting are presented for both rigidly and elastically coupled damping. Easily obtainable closed solutions for the slipping and sticking phases of the motion are used in the method, and no conceptual approximation is involved. The transmissibility curves are compared with previously published approximations based on linearization of the damping. It is shown that the approximate method seriously underestimates the heights of significant resonant peaks and gives optimum friction values which are somewhat in error, but gives reasonable approximations to the transmissibilities at the high frequencies corresponding to effective isolation.

● **6.2-60** Ueda, T., **Non-linear free vibrations of conical shells,** *Journal of Sound and Vibration,* **64**, *1*, May 8, 1979, 85-95.

The nonlinear characteristics of the free vibrations of conical shells, including circular cylinders and annular plates as special cases, are investigated. Donnell-type theory is utilized to prescribe the shells, and the trial functions of the assumed mode are obtained by means of

● *See* ***Preface****, page v, for availability of publications marked with dot.*

the finite element method. The method of weighted residuals applied to time variables furnishes the nonlinear algebraic equations to be solved for the dependency of the frequency upon the amplitude. Comparisons of the results with those obtained in previous investigations are made for a cylinder and for an annular plate. The numerical results elucidate the characteristics of the softening type of vibrations of conical shells with fixed edges which have a ratio of slant length to the small radius of 1·6125 and a ratio of thickness to the small radius of $1 \cdot 25 \times 10^{-3}$.

● **6.2-61** Cawley, P. and Adams, R. D., **Improved frequency resolution from transient tests with short record lengths,** *Journal of Sound and Vibration,* **64,** *1,* May 8, 1979, 123-132.

A method is described for improving the accuracy of the natural frequencies obtained from the Fourier transform of the structural response to an impulse. Results are presented from tests in which the input was at a single frequency and from impulse tests on an aluminum plate. It is shown that it is possible to obtain a frequency resolution of one-tenth of the spacing between the frequency points produced by the Fourier transform at a low cost in terms of computer time and storage. The natural frequencies of the aluminum plate obtained by this method are compared with those measured when using steady-state excitation. Excellent agreement is shown between the results obtained by using the two techniques.

● **6.2-62** Sathyamoorthy, M., **Effects of large amplitude, shear and rotatory inertia on vibration of rectangular plates,** *Journal of Sound and Vibration,* **63,** *2,* Mar. 22, 1979, 161-167.

In this paper, the governing equations applicable for the large amplitude free flexural vibration of orthotropic rectangular plates are formulated in terms of the displacement components u, v, and w. The formulation and the solutions presented for the cases of isotropic and orthotropic simply supported rectangular plates incorporate the effects of the transverse shear deformation and the rotatory inertia on the large amplitude vibration behavior. The influences of shear and rotatory inertia are significant in the case of moderately thick plates undergoing large amplitude vibration. The method suggested does not require the use of the Berger approximation for plates with immovable inplane edge conditions. A comparison with the results available in the literature indicates the inadequacy of the approach adopted earlier for the study of the large amplitude free flexural vibration of orthotropic rectangular plates.

● **6.2-63** Takahashi, K., **Non-linear free vibrations of inextensible beams,** *Journal of Sound and Vibration,* **64,** *1,* May 8, 1979, 31-34.

Nonlinear free vibrations of inextensible clamped-free and free-free beams are analyzed by using Galerkin's method and the harmonic balance method.

● **6.2-64** Adham, S. A. and Ewing, R. D., **Methodology for mitigation of seismic hazards in existing unreinforced masonry buildings, phase I,** Agbabian Assoc., El Segundo, California, Mar. 1978, 93. (NTIS Accession No. PB 287 898)

A program with several phases has been initiated to develop a methodology for the mitigation of seismic hazards in existing unreinforced masonry (URM) buildings. The present research, part of Phase 1, identifies trends in the seismic response of the components of URM buildings and determines what studies and testing are necessary to arrive at a methodology that can be used throughout the nation. The response of plywood, diagonal-sheathed, and straight-sheathed diaphragms, represented by lumped-mass mathematical models, was studied. Experimental data on static loading and unloading were used. Both local and distant earthquake ground motions were used as input. The results show that the diaphragm response is strongly dependent on the long-period content of the input. The response of masonry walls subjected to in-plane earthquake ground motion was also studied. The analytical results show that the model used can reasonably predict the response of the wall as a function of its height-to-width ratio and the stiffness of the supporting soil. The report evaluates methods for selecting earthquake ground-motion input at a site in the United States and describes analysis methods that can be used to determine the response of URM buildings to earthquake forces.

● **6.2-65** Prathap, G. and Varadan, T. K., **Non-linear flexural vibrations of anisotropic skew plates,** *Journal of Sound and Vibration,* **63,** *3,* Apr. 8, 1979, 315-323.

The large amplitude, free flexural vibrations of thin, elastic, anisotropic skew plates are studied by using the von Karman field equations in which the governing nonlinear dynamic equations are derived in terms of the stress function and the lateral displacement. Clamped boundary conditions are chosen, and the in-plane edge conditions considered are either immovable or movable. Solutions are obtained by the Galerkin method on the basis of a one-term assumed vibration mode. The degree of nonlinearity is obtained as a function of skew angle, aspect ratio, and types of orthotropy. The results, when specialized for an isotropic skew plate and an orthotropic rectangular plate, agree well with those found in the literature. The use of the Berger approximation to study a skew plate with inplane immovable edges is shown to lead to errors of both a quantitative and qualitative nature.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **6.2-66** Mukhopadhyay, M., **A semi-analytic solution for free vibration of annular sector plates,** *Journal of Sound and Vibration,* **63,** *1,* Mar. 8, 1979, 87-95.

This paper describes a semi-analytical method in which the basic function in the circumferential direction satisfying the boundary conditions of the radial edges is substituted into the free vibration equation of the curved plate. By a suitable transformation, an ordinary differential equation is obtained. The resulting equation is solved by a finite difference technique. Tabulated results are presented for annular sector plates possessing different boundary conditions. Excellent accuracy is obtained for the comparisons made.

● **6.2-67** Nagaya, K., **Vibration of a viscoelastic plate having a circular outer boundary and an eccentric circular inner boundary for various edge conditions,** *Journal of Sound and Vibration,* **63,** *1,* Mar. 8, 1979, 73-85.

In this paper, the vibration problems of a circular viscoelastic plate having an eccentric circular inner edge are investigated. The frequency equations in complex forms for various edge conditions are obtained. Numerical calculations are carried out for elastic and viscoelastic plates, and the nondimensional natural frequencies and the logarithmic decrements are given for a number of cases.

● **6.2-68** Sharma, C. B., **Vibration characteristics of thin circular cylinders,** *Journal of Sound and Vibration,* **63,** *4,* Apr. 22, 1979, 581-592.

In this paper, a unified treatment is given to the problems of the vibration characteristics of thin circular cylindrical shells with various end conditions by using the kinematic relations of Sanders' first-order shell theory. A simple variational technique is applied to give a cubic frequency equation. This cubic frequency equation is reduced to two simple linear relations for the frequency parameter by incorporating an engineering approximation relating deflections in two different ways: (1) in general, and (2) in the inertia components only. It is shown that the linear formula obtained by (2) is much superior to that obtained by (1) and is also superior to the much more complicated cubic equation to some extent. Expressions for evaluating mode shapes are also given. Results found by using the present technique are compared with some previous exact analysis results. Frequencies calculated for a cylinder are shown to be in good agreement with some available observed results.

● **6.2-69** Elishakoff, I., van Zanten, A. Th. and Crandall, S. H., **Wide-band random axisymmetric vibration of cylindrical shells,** *Journal of Applied Mechanics, ASME,* **46,** 2, June 1979, 417-422.

Analytical and numerical results are reported for the random vibrations of a uniform circular cylindrical shell excited by a ring load which is uniform around the circumference and random in time. The time history of loading is taken to be a stationary wide-band random process. The shell response is essentially one-dimensional but differs qualitatively and quantitatively from the response distributions for point-excited uniform strings and beams because of the large modal overlaps at the low end of the spectrum of the natural frequencies of the shell. The contributions from the modal cross-correlations (which can usually be neglected for strings and beams) introduce an asymmetry into the distribution of mean-square response and can alter the magnitude of the local response considerably. For example, in a thin shell with a radius-to-length ratio of 0.5, the contribution to the mean-square velocity at the driven section from the modal cross-correlations can be more than three times that from the modal autocorrelations when the excitation is a band-limited white noise which includes 81 modes.

● **6.2-70** Soedel, W. and Powder, D. P., **A general Dirac delta function method for calculating the vibration response of plates to loads along arbitrarily curved lines,** *Journal of Sound and Vibration,* **65,** *1,* July 8, 1979, 29-35.

A general Dirac delta function description of line loads along arbitrarily curved lines is developed. The method is used to solve several example problems that illustrate dynamic (or static) line loading: (1) along a line parallel to a coordinate axis, (2) along the diagonal, (3) along any straight line, and (4) along an arbitrarily curved line. It is argued that this approach results in simpler integrals than the traditional approach in which the load is first visualized to be distributed over a strip of finite width; after the solution of this problem, the width is made to approach zero. In some cases, it is the only feasible approach if a closed-form solution is desired.

● **6.2-71** Raju, K. K. and Rao, G. V., **Nonlinear vibrations of tapered circular plates elastically restrained against rotation at the edges,** *Nuclear Engineering and Design,* **51,** 3, Feb. 1979, 417-421.

The large amplitude free vibration characteristics of tapered circular plates elastically restrained against rotation are studied using the finite element method. The linear frequency parameter and ratios of nonlinear to linear periods are obtained for various values of the rotational spring and taper parameters and are presented in tabular form.

● **6.2-72** Murray, D. W., **Octahedral based incremental stress-strain matrices,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM4,* Proc. Paper 14734, Aug. 1979, 501-513.

● *See **Preface,** page v, for availability of publications marked with dot.*

Some investigators have recently suggested that appropriate nonlinear stress-strain relationships for concrete can be obtained by deriving expressions for bulk and shearing moduli based upon experimental data presented in terms of octahedral stresses and strains. This paper reviews octahedral stress-strain relationships and derives appropriate stiffness matrices, both secant and tangent, for plane stress, plane strain, and three-dimensional applications. It is shown that proper tangent stiffness matrices cannot be obtained simply by replacing secant moduli with tangent moduli. Incremental matrices suitable for implementation in nonlinear finite-element programs are presented and considered.

● 6.2-73 White, R. N. and Gergely, P., **Shear transfer in thick walled reinforced concrete structures under seismic loading,** *Report 78-2,* Dept. of Structural Engineering, Cornell Univ., Ithaca, New York, May 1978, 240.

The research project reported in this paper had three major goals: (1) to understand the mechanism of cyclic shear stress transfer in cracked thick-walled reinforced concrete structures; (2) to incorporate mathematical models of the shear transfer mechanism into computer-based analysis methods for determining structural response to earthquakes; and (3) to provide experimental and analytical background material for the formulation of improved design procedures that would result in better and less costly designs. Extensive experiments on large specimens of cracked concrete were conducted. Shear transfer by interface shear transfer on the rough cracked surfaces, as well as shear transfer by dowel action of reinforcing crossing the crack, were studied for a wide range of variables. The degradation of the shear transfer mechanism with continued cycling of shear stress was of particular concern and importance in the experiments. It was found that cyclic shear stresses on the order of 200 psi could be carried quite efficiently by this mechanism. The behavior of both the concrete and steel in the structure can be predicted with reasonable accuracy on the basis of experimental evidence. Final reduction of all data into a comprehensive, simplified model of behavior is being conducted now under a continuation of this project. The computer-based analysis program completed during the study gives reliable predictions of forces, stresses, overall deformations, and displacements of thick-walled concrete structures subjected to earthquake forces. Prior to these shear transfer studies, diagonally oriented reinforcing steel was normally required to resist the entire seismic shear stress in reinforced containment vessels and similar structures. Now it is possible to rely upon some shear transfer capacity from the combination of normal vertical and horizontal steel and the inherent roughness of the crack surface in the concrete. This saves reinforcing steel and permits a more rational design.

6.2-74 Banerjee, B. and Datta, S., **Large amplitude vibrations of thin elastic plates by the method of conformal transformation,** *International Journal of Mechanical Sciences,* **21,** *11,* 1979, 689-696.

A unified method is presented for investigating the large amplitude vibrations of thin elastic plates of any shape under clamped edge boundary conditions. The method is based on Von Karman governing equations generalized to the dynamic case. The conformal mapping technique is introduced, and the domain is conformally transformed onto the unit circle. The deflection function is chosen beforehand in conformity with the prescribed boundary conditions. The stress function is solved taking only the first term of the mapping function. The transformed differential equations are solved by the Galerkin procedure to obtain the second-order nonlinear differential equation for the unknown time function. The time equation is readily solved in terms of Jacobian elliptic functions. The frequency of linear and nonlinear oscillations, as well as the static nonlinear case, are analyzed for plates of circular and regular polygonal shapes. Results obtained are compared with other known results. From the comparative study of different results, it is observed that the first-term approximation of the mapping function yields fairly accurate results with less computational effort.

6.2-75 Renton, J. D., **An analysis of the static and dynamic instability of thick cylinders,** *International Journal of Mechanical Sciences,* **21,** *12,* 1979, 747-754.

A general solution of Bolotin's differential equations is given for the dynamic stability of a homogenous isotropic medium. Displacement functions express the solution as a sum of dilatational and distortional effects. Using these functions, solutions are found for the vibration of cylinders of finite thickness when initial axial stresses are present. The behavior of solid rods, simple vibration, and simple buckling are all seen to be special cases of the general solution. The results are compared with approximate formulas for the buckling of thin cylinders, and it is shown that the known solution for the natural frequency of unloaded cylinders is a particular case.

6.2-76 Nagaya, K., **Approximate dynamic analysis of Timoshenko beams and its application to tapered beams,** *The Journal of the Acoustical Society of America,* **66,** *3,* Sept. 1979, 794-800.

An approximate method of analysis for the dynamic response problems of a Timoshenko beam is presented in this paper. The results for the beam are obtained by the addition of the solution for bending and rotatary motions, and the results for the shear motion are obtained by neglecting the inertia force of the shear motion. The results by this analysis are compared with exact results for Timoshenko and Bernoulli-Euler beams. Dynamic response

● *See **Preface,** page v, for availability of publications marked with dot.*

problems of taper beams with a moving load are solved by this method.

6.2-77 Kaisand, L. R. and Mowbray, D. F., **Relationships between low-cycle fatigue and fatigue crack growth rate properties,** *Journal of Testing and Evaluation,* **7,** *5,* Sept. 1979, 270-280.

A fracture mechanics model is developed in this paper to describe crack growth in a low-cycle fatigue test specimen. The model involves a J integral analysis and a growth rate hypothesis in terms of ΔJ. A relationship for low-cycle fatigue is derived that has strain energy density as the controlling variable. This relationship reduces to well-known low-cycle fatigue equations in terms of elastic and plastic strains for the limiting conditions of fully elastic and fully plastic strain fields. These equations in turn define relationships between the material properties commonly employed to describe low-cycle fatigue and fatigue crack growth rate data. The latter are used to demonstrate the facility of predicting fatigue crack growth rate curves from standard low-cycle fatigue properties.

6.2-78 Chan, H. C. and Cheung, Y. K., **Analysis of shear walls using higher order finite elements,** *Building and Environment,* **14,** *3,* 1979, 217-224.

Shear walls can be simply and conveniently modeled by using higher order plane-stress finite elements which have a higher degree of variation in the displacement, and consequently the stress, functions. The derivation and generation of the stiffness matrices by a computer subroutine for a series of higher order plane-stress rectangular elements with any number of nodes are explained in detail and the elements are applied in the idealization of different types of shear walls in which the spandrel beams and openings are treated as a continuum. Three examples of shear wall problems are analyzed to illustrate the simplicity, versatility, and accuracy of this method as compared with the results of other available methods.

● **6.2-79** Shiau, J.-J., **Simplified analysis of vertical vibrations,** *Journal of the Energy Division, ASCE,* **105,** *EY2,* Proc. Paper 14750, Aug. 1979, 251-264.

Interactions of vertical vibrations among building systems consisting of slabs, beams, girders, and columns are rather complex. Finite element dynamic analysis for the vertical direction is not only costly in modeling and computer time but also subjected to the limitation of available computer core sizes. The importance and benefit of using simplified analyses of vertical vibration become obvious. In this paper, simplified equations of vertical motion are derived in a general manner to include n modes of all subsystems. Theoretically, n is from 1 to infinity. Two examples are included. The first example illustrates procedures used to set up the simplified equations of vertical motion, according to the general expressions derived in this paper. The second example shows the validity of the simplified analysis by comparing the results with those from the finite element analysis.

● **6.2-80** Rahmathullah, R. and Mallik, A. K., **Damping of cantilever strips with inserts,** *Journal of Sound and Vibration,* **66,** *1,* Sept. 8, 1979, 109-117.

The possibility of improving the damping capacity of cantilever strips by using high-damping inserts has been studied experimentally. Results are presented for an aluminum strip with solid and annular inserts of three different materials: cast iron, bakelite, and perspex. The material-damping characteristics of all four materials are calculated from the specimen damping obtained from the free vibration records of cantilever strips. It is shown that with a proper choice of insert material, considerable improvement of damping capacity can be attained by using very little of the high-damping material.

● **6.2-81** Kerstens, J. G. M., **Vibration of a rectangular plate supported at an arbitrary number of points,** *Journal of Sound and Vibration,* **65,** *4,* Aug. 22, 1979, 493-504.

A method is described for establishing the natural frequencies of a rectangular plate supported at points. The number and the location of these points may be completely arbitrary. The method is based on extensions to the intermediate problem technique of Aronszjan and Weinstein through the use of finite sets of constraints. The method is called the modal constraint method. Its merits lie in the fact that the eigenvalues and eigenfunctions of a completely free vibrating rectangular plate are used as the reference structure. The modifications associated with the point supports are taken into account by Lagrangian generalized forces of constraint acting on the reference structure. The method has been verified with many known solutions. Furthermore, the convergence to exact known natural frequencies is accomplished very quickly with any desired degree of accuracy.

● **6.2-82** Celep, Z., **Axially symmetric stability of a completely free circular plate subjected to a non-conservative edge load,** *Journal of Sound and Vibration,* **65,** *4,* Aug. 22, 1979, 549-556.

This paper presents a study on the behavior of the vibration and stability of a two-dimensional structure, i.e., a completely free circular plate subjected to nonconservative radial loading. The eigencurves and mode shapes of the circular plate are presented for various values of the nonconservativeness parameter. Some interesting conclusions concerning the behavior of a completely free plate are drawn from the analytical investigation of the solution of the problem and from numerical calculations.

● *See **Preface,** page v, for availability of publications marked with dot.*

● **6.2-83** Saito, H. and Mori, K., **Vibrations of a beam with non-linear elastic constraints,** *Journal of Sound and Vibration,* **66,** *1,* Sept. 8, 1979, 1–8.

The transverse vibrations of a beam, with both ends supported on nonlinear elastic constraints, carrying a concentrated mass and subjected to a transverse periodic force, are analyzed. The nonlinear constraints are represented by rotational and translational springs having both linear and cubic nonlinear behavior. The harmonic responses of a beam involving the third-order superharmonic and the one-third-order subharmonic are considered. The beam responses to the effects of nonlinear elastic constraints are illustrated in two example cases.

● **6.2-84** Avalos, D. R. and Laura, P. A. A., **A note on transverse vibrations of annular plates elastically restrained against rotation along the edges,** *Journal of Sound and Vibration,* **66,** *1,* Sept. 8, 1979, 63–67.

The title problem is solved by using simple polynomial expressions whch identically satisfy the boundary conditions. A variational method is applied in order to generate a frequency determinant. Whenever possible, the results are compared with previously published values and very good agreement is shown to exist.

● **6.2-85** Lunden, R., **Optimum distribution of additive damping for vibrating beams,** *Journal of Sound and Vibration,* **66,** *1,* Sept. 8, 1979, 25–37.

Cost and weight effectiveness of concentrated and distributed additive damping is studied for discrete and continuous linear systems under prescribed harmonic loads and/or displacements. Stiffness and mass changes caused by additive damping are included. From a numerical example, it can be concluded that optimal damping distributions can reduce resonant responses by about 40% as compared to uniformly distributed damping of the same cost or weight. The optimization technique and an exact displacement method for analysis of harmonically vibrating beams and frames are presented.

● **6.2-86** Wada, H., **Forced torsional vibrations of a cylindrical rod connected to an elastic half-space,** *Journal of Sound and Vibration,* **66,** 2, Sept. 22, 1979, 265–275.

An analysis is presented of the forced torsional vibrations of a cylindrical rod connected to an elastic halfspace under the condition that the circumferential displacement at the free end of the rod, where the disturbing moment is applied, varies proportionally with the distance from the rod axis. Both the Pochhammer-Chree and elementary theories are utilized. The response curve of the rotational amplitude at the free end of the rod, obtained from the Pochhammer-Chree theory, and the response curve obtained from the elementary theory almost coincide with each other except in the case where the rod and the halfspace are of the same material. The amplitude attenuation is largest when the rod and the halfspace are of the same material. The maximum values of halfspace displacement distribution at the interface lie within the rod edge.

● **6.2-87** Gorman, D. J., **Solutions of the Levy type for the free vibration analysis of diagonally supported rectangular plates,** *Journal of Sound and Vibration,* **66,** *2,* Sept. 22, 1979, 239–246.

A Levy-type solution is developed for the vibratory response of a simply supported rectangular plate subjected to a harmonic force distributed along the diagonal. The solution is then extended to determine the free vibration response of the same rectangular plate with inelastic lateral support on the diagonal. It is found that there is an excellent agreement between computed eigenvalues obtained here and those obtained by the author in an earlier paper in which a Navier-type solution was utilized. The significant advantages inherent in the present Levy-type solution are discussed.

● **6.2-88** Irie, T., Yamada, G. and Aomura, S., **Free vibration of a Mindlin annular plate of varying thickness,** *Journal of Sound and Vibration,* **66,** 2, Sept. 22, 1979, 187–197.

The free vibration of a Mindlin annular plate of radially varying thickness is analyzed by use of the transfer matrix approach. For this purpose, the Mindlin equations of flexural vibration of an annular plate are written as a coupled set of first-order differential equations by using the transfer matrix of the plate. Once the matrix has been determined by the numerical integration of the equations, the natural frequencies and the mode shapes of the vibration are calculated numerically in terms of the elements of the matrix for a given set of boundary conditions at the edges of the plate. This method is applied to annular plates of linearly, parabolically, and exponentially varying thickness, and the effects of the varying thickness are studied.

● **6.2-89** Pritz, T., **Choice of thickness ratio of a coated beam used for investigating the complex modulus of viscoelastic materials,** *Journal of Sound and Vibration,* **66,** 2, Sept. 22, 1979, 155–164.

The coated beam method has been widely used for investigating the complex modulus of elasticity of relatively soft viscoelastic materials, e.g., materials for vibration damping. With this method, a rectangular-section metal beam is coated with the viscoelastic material on one side, or symmetrically on both sides, and the resonances of the bending vibration of the beam are investigated. In this paper, a procedure is described for finding the ratio of coating thickness to metal thickness required to obtain

● *See **Preface**, page v, for availability of publications marked with dot.*

accurate results for the complex modulus in such investigations. The contradiction experienced earlier—that a relatively large thickness ratio is required for precision while the resonance method demands a small thickness ratio—is analyzed mathematically. The relationships derived serve as a basis for optimizing the choice of the ratio. Diagrams and a procedure for the optimization are presented. Experimental results obtained with suitable and unsuitable thickness ratios are discussed.

● 6.2-90 Davies, J. M. and Fisher, J., **The diaphragm action of composite slabs**, *Proceedings, The Institution of Civil Engineers*, Part 2, **67**, Paper No. 8271, Dec. 1979, 891-906.

Composite floor slabs consisting of profiled steel sheeting and in-situ concrete topping act as horizontal diaphragms and attract significant in-plane loads. In this paper, the diaphragm action of composite slabs fastened to the primary structure with mechanical fasteners such as self-drilling, self-tapping screws is considered. Four full-scale tests on cantilever diaphragms are described and three failure modes identified. A theory is then developed whereby the strength and flexibility may be predicted. The prediction of strength shows adequate accuracy but the prediction of flexibility is found to be applicable only when a diaphragm is reloaded. The calculation of the initial flexibility is shown to be difficult because there is a relatively large initial movement before full composite action is developed.

● 6.2-91 Hamid, A. A., Drysdale, R. G. and Heidebrecht, A. C., **Shear strength of concrete masonry joints**, *Journal of the Structural Division, ASCE*, **105**, *ST7*, Proc. Paper 14670, July 1979, 1227-1240.

The experimental results of 46 shear tests of ungrouted and grouted concrete block masonry are reported. The shear specimens were tested under shear along the bed joints. The influence of mortar type, grout strength, bed-joint reinforcement, and level of compressive stress normal to the bed joints was studied. The results indicate that the strength characteristics of the mortar joint do not have a major effect on the resistance of masonry joints to shear-slip failure. The grout strength and the normal compressive stress are the most significant parameters influencing the joint capacity. The relative contribution of grouting to increasing the joint shear strength decreases as the level of precompression increases. A strong correlation between the shear strength and the normal compressive stress is shown to exist for both ungrouted and grouted masonry under low levels of precompression.

● 6.2-92 Kar, A. K., **Seismic support: speedy determination of frequency**, *Journal of the Structural Division, ASCE*, **105**, *ST7*, Proc. Paper 14672, July 1979, 1289-1306.

Seismic restraints are provided to support safety-related electrical cable trays or conduits and heating, ventilation, and air conditioning (HVAC) ductwork in nuclear power plant structures. It is shown that most of these restraints, in the form of frames, can be represented by single degree-of-freedom models for analysis and design. Approximate formulas, based on the stiffness of the single degree-of-freedom models, are presented to determine the natural frequencies quickly and reliably. The formulas have the added advantage of demonstrating the contribution of different members to the frequency of a frame. The use of the formulas presented in the paper can considerably simplify the dynamic analysis of seismic supports for electrical cables and HVAC ducts in nuclear power plants and other structures.

● 6.2-93 Drysdale, R. G., Hamid, A. A. and Heidebrecht, A. C., **Tensile strength of concrete masonry**, *Journal of the Structural Division, ASCE*, **105**, *ST7*, Proc. Paper 14669, July 1979, 1261-1276.

Sixty-three masonry disks were tested under splitting loads having different orientations from the bed joint direction. The influences of mortar type, grout strength, and bed joint reinforcement were studied. The results show that the tensile strength characteristics of either ungrouted or grouted masonry vary with the stress orientation that indicates the inherent anisotropic nature of masonry as a composite material. The contribution of grouting varies substantially with the stress orientation. Grouting has a maximum contribution under tension stress normal to the bed joint and a negligible contribution under tension stress parallel to the bed joint. The mortar type has little influence on the tensile strength. The bed joint reinforcement only contributes to the capacity under tension stresses parallel to the bed joint.

● 6.2-94 Beskos, D. E., **Dynamics and stability of plane trusses with gusset plates**, *Computers & Structures*, **10**, *5*, Oct. 1979, 785-795.

The effect of gusset plates on free and forced vibration and stability analyses of plane trusses is investigated in this paper. The gusset plates are considered to be finite joints possessing mass and rotational flexibility. The bars of the truss are assumed to be elastic Bernoulli-Euler beams with distributed mass. Axial deformation of the bars and the effect of a constant axial force on the bending stiffness are taken into account. On the basis of these assumptions, element stiffness matrices are constructed and presented in detail. The general formulation and solution of stability and free and forced vibration problems of trusses is discussed. Examples are presented in detail which demonstrate the effect of the gusset plates on the behavior of trusses under static or dynamic loads.

● **6.2-95** Mizusawa, T., Kajita, T. and Naruoka, M., **Vibration of stiffened skew plates by using *B*-spline functions,** *Computers & Structures,* **10,** *5,* Oct. 1979, 821–826.

This paper presents a general procedure for calculating the free vibration of stiffened skew plates by the Rayleigh-Ritz method with *B*-spline functions as coordinate functions. The stiffened skew plates are modeled as the skew plate with a number of stiffening beams. The results are compared with existing values based on other numerical methods. Vibration characteristics of stiffened skew plates are also studied by changing the arrangements of stiffening beams, the stiffness parameters of beams, skew angle, and aspect ratio.

● **6.2-96** Reddy, V. M., Reddy, K. N. and Sarma, A. S., **A confined concrete theory for the behaviour of eccentrically loaded columns,** *Journal of the Institution of Engineers (India),* **59,** *Part CI 5,* Mar. 1979, 313–318.

A confined concrete theory is proposed to study the behavior of eccentrically loaded rectangular reinforced concrete columns with uniaxial eccentricity with respect to ultimate load and moment curvature relations near the ultimate stage. The theoretical work is verified with the results of tests on 45 column specimens. The main parameters in the investigation are the spacings of lateral binders, which confine the concrete and the eccentricity of the axial loading.

● **6.2-97** Rangan, B. V., **Shear strength of partially and fully prestressed concrete beams,** *UNICIV Report R-180,* School of Civil Engineering, Univ. of New South Wales, Kensington, Australia, Feb. 1979, 17.

This paper develops an equation for the calculation of the shear force carried by concrete in regions of structural concrete beams cracked in flexure. The proposed expression shows good agreement with the numerous test data available in the literature. The new formula has the advantage that it can be applied to an entire range of structural concrete members from reinforced concrete beams to fully prestressed concrete beams.

● **6.2-98** Derecho, A. T. et al., **Structural walls in earthquake-resistant buildings—dynamic analysis of isolated structural walls: parametric studies,** Construction Technology Labs., Portland Cement Assn., Skokie, Illinois, Mar. 1978, 228.

The primary objective of the analytical investigation of which this report is a part is the estimation of maximum forces and deformations that can reasonably be expected in critical regions of structural walls of buildings subjected to strong ground motion. The results of the analytical investigation, when correlated with data from the concurrent experimental program, will form the basis for the design procedure which is the ultimate objective of the entire investigation.

This is the second part of a comprehensive report on the analytical investigation. The results of parametric studies of various structural and ground motion parameters are discussed. These parameters are examined in terms of their effects on the dynamic inelastic response of isolated structural walls. Among the structural parameters considered are fundamental period, yield level, yield stiffness ratio, character of the hysteretic force-displacement loop (reloading and unloading stiffnesses) damping, stiffness and strength taper, and degree of base fixity. Also considered are the three parameters characterizing stong-motion accelerograms: duration, intensity, and frequency content.

6.2-99 Desayi, P., Iyengar, K. T. S. R. and Reddy, T. S., **Stress-strain characteristics of concrete confined in steel spirals under repeated loading,** *Matériaux et Constructions,* **12,** *71,* Sept.-Oct. 1979, 375–383.

Repeated loading tests have been conducted on concrete cylinders 150 mm in diameter and 300 mm high with a circular steel spiral confining the concrete. Stress-strain curves obtained in the experiments are presented. Equations are proposed for the envelope, unloading, and reloading curves of the stress-strain curves. These equations are compared with test results.

● **6.2-100** Iwata, Y. and Kobori, Y., **Free vibration of cylindrical shell** (in Japanese), *Memoirs of the Faculty of Technology, Kanazawa University,* **12,** *1,* Mar. 1979, 45–54.

Several vibrations of a thin cylindrical shell are analyzed by the finite element method. In earlier reports, both the stiffness matrix and the mass matrix of the cylindrical shell elements consisted of complicated expressions. This paper shows that the stiffness matrix and the mass matrix can be simply expressed and easily evaluated. By using the method presented in this paper, the natural frequencies and the natural modes of the cantilevered cylindrical shell are derived. These calculations agree with experimental results. The relationships between the natural frequencies and the natural modes and the size of the cylindrical shell are studied, and the characteristics of the vibrations of the cylindrical shell are as follows: (1) natural frequencies and natural modes of the cylindrical shell depend on the generating line ratio, the central angle, and the thickness ratio; (2) natural frequencies and natural modes of the cantilevered cylindrical shell differ remarkably from those of the plate; and (3) in the case of vibrations of the cantilevered cylindrical shell, the node lines tend to occur in the direction of the generating line.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.2-101** Sato, H., **Nonlinear vibrations of stepped beams** (in Japanese), *Memoirs of the Faculty of Technology, Kanazawa University*, **12**, *1*, Mar. 1979, 55–64.

The nonlinear vibration of beams whose cross sections vary in steps in the longitudinal direction is investigated using the transfer matrix method. Means of analysis are proposed for both free and forced vibrations. As a numerical example, the first mode free vibrations of clamped beams with two symmetric steps are analyzed. The effects of beam shape on the nonlinearity of vibration are discussed in detail. It is shown that the use of the linear mode function results in considerable overestimation of the nonlinearity for beams of a certain type. An experiment is carried out to verify the calculated results using a two-step beam made of phosphor bronze. The experimental results show good agreement with the calculated results.

● **6.2-102** Victor, F. H. and Ellyin, F., **Assemblage method for folded-plate analysis,** *Journal of the Structural Division, ASCE*, **105**, *ST7*, Proc. Paper 14689, July 1979, 1509–1524.

A method is proposed for the elastic analysis of isotropic or orthotropic folded plate structures. In this method, harmonic functions that satisfy the boundary condition in the longitudinal direction are used in conjunction with exponential functions for the transverse direction. Stiffness matrices for both "bending" and "in-plane" actions have been developed for a plate with an orthotropic elastic property by dividing the folded plate structure into a number of plate elements bounded geometrically by lines of fold. Any combination of loadings may be considered. After obtaining the joint displacements, the stresses and displacements at any point of the structure are readily calculated. A special digital computer program is developed for the analysis.

● **6.2-103** Rutenberg, A., **Vibration properties of curved thin-walled beams,** *Journal of the Structural Division, ASCE*, **105**, *ST7*, Proc. Paper 14687, July 1979, 1445–1455.

A simple procedure is proposed to evaluate the out-of-plane vibration frequencies for a class of horizontally curved beams. The two governing differential equations are first partly uncoupled by means of a linear transformation. When the remaining coupling terms cannot be neglected, a two degree-of-freedom solution is obtained by taking advantage of the similarity between the two uncoupled mode shapes. The method yields an exact solution only for simply supported curved beams. For other support conditions, the solution is approximate. The method is illustrated by a numerical example: a fixed-fixed curved highway with an open cross section.

● **6.2-104** Jimenez-Perez, R., Gergely, P. and White, R. N., **Shear transfer across cracks in reinforced concrete,** *Report 78-4*, Dept. of Structural Engineering, Cornell Univ., Ithaca, New York, Aug. 1978, 357.

This report describes an experimental and analytical investigation conducted to assess the transfer of cyclic shear forces in cracked reinforced concrete by means of the interface shear transfer and dowel action mechanisms. The research was originally motivated by the need to understand the transfer of membrane shear stresses induced by seismic activity across precracked concrete surfaces in secondary nuclear containment vessels. However, the results can be applied to other situations when shear forces have to be transferred across cracked concrete surfaces reinforced with large-diameter bars. The experimental program consisted of two test series which evaluated the transfer of shear forces by (1) the combination of the interface shear transfer and dowel action mechanisms, and (2) the dowel action mechanism alone. The initial crack width and the reinforcement ratios provided at the shear plane, the number of loading cycles, and the cyclic shear stress intensity were the main variables studied using a test specimen modeled after an idealized section of the cracked structure. The average shear displacement, crack width, and reinforcement strains were measured in each specimen for all load increments.

Simplified equations were developed to describe the stiffness of the first loading cycle exhibited by both the interface shear transfer and the dowel action mechanism. A bilinear idealization was proposed for the experimental hysteresis curve of each mechanism together with the corresponding stiffness coefficients. These idealized hysteresis curves were combined by equilibrium and compatibility requirements present at the shear plane to obtain the hysteresis curves exhibited by the combined action of both mechanisms. Equations were derived from a nonlinear regression analysis for the splitting failure force for axial or dowel forces, and for their interaction. An equation was also proposed for the ultimate shear stress that can be transferred across a precracked shear plane.

The research concluded that shear forces can be efficiently transferred across cracked surfaces by the combined action of the interface shear transfer and dowel action mechanisms. For the specimens tested, the interface shear transfer mechanism sustained between 65 and 80% of the total applied shear, while the dowel action mechanism was responsible for 35 to 20% of the total shear. Cyclic loading increases the shear displacement at the crack, the crack width, and the bar strains. These rates of increase, however, are highly dependent on the reinforcement ratio and on the applied shear stress intensity. Large-diameter bars enhance the probability of concrete splitting along the reinforcement longitudinal axis. The equations derived on the basis of a splitting failure model agree reasonably well with the experimental data available. Previous experimental information on small diameter bars should not be applied to describe the behavior of large-diameter bars without additional experimental evidence.

6.2-105 Yakupov, R. G., **Effect of an explosion wave on a cylindrical panel** (Deistvie vzryvnoi volny na tsilindricheskuyu panel', in Russian), *Stroitel'naya mekhanika i raschet sooruzhenii*, *1*, Feb. 1979, 35–39.

Deflections, stresses, and stability of a shallow cylindrical panel, immersed in a continuous medium and impacted by a plastic shock wave generated as a result of an explosive detonation, are determined. The problem is solved with the aid of the Bubnov-Galerkin method. An illustrative example is cited. Results can be applied to determination of safe distances from an explosion, and to determination of the explosive charge.

● **6.2-106** Elias, Z. M., **Sidesway analysis of flat plate structures**, *Journal of the American Concrete Institute*, **76**, *3*, Title No. 76-20, Mar. 1979, 421–442.

The ACI equivalent frame method is not appropriate for sidesway analysis of flat slab structures. A method is developed for discretizing a flat plate panel into an equivalent beam; practical formulas are presented for computing the stiffness matrix of the equivalent beam. An equivalent frame method for sidesway analysis is developed based on equivalent beams and unmodified columns.

● **6.2-107** Kanoh, Y. and Yoshizaki, S., **Strength of slab-column connections transferring shear and moment**, *Journal of the American Concrete Institute*, **76**, *3*, Title No. 76-22, Mar. 1979, 461–478.

Various methods for predicting the strength of slab-column connections that transfer shear force and moment have been proposed, but in all those methods calculated values are conservative when compared to the measured strengths. That conservatism is caused by an underestimation of the moment which is transferred between the slab and the column by torsion. Torsion tests of slab-column connections were carried out to directly investigate the magnitude of the moment that can be transferred by torsion. In this paper, those tests are described and a method for predicting the strength of slab-column connections transferring shear and moment is proposed which compares well to available test data.

● **6.2-108** Derecho, A. T. et al., **Strength, stiffness, and ductility required in reinforced concrete structural walls for earthquake resistance**, *Journal of the American Concrete Institute*, **76**, *8*, Title No. 76-37, Aug. 1979, 875–896.

Observations of building performance in recent earthquakes have indicated that structures stiffened by properly proportioned and designed reinforced concrete structural walls (shear walls) behaved better than relatively more flexible moment-resisting open frames. This paper presents some results of a combined analytical and experimental program to develop design information for earthquake-resistant reinforced concrete structural walls and wall systems. The principal objective of the investigation is the development of a procedure for determining design force levels for earthquake-resistant structural walls. The results of over 300 analyses form the basis of the procedure, which involves a correlation with relevant results of the concurrent experimental investigation.

● **6.2-109** Scribner, C. F. and Wight, J. K., **Delaying shear strength decay in reinforced concrete flexural members under large load reversals**, *UMEE 78R2*, Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, May 1978, 221.

Eight half-sized and four full-sized T-shaped reinforced concrete exterior beam-column subassemblies were tested to determine the effect of intermediate longitudinal shear reinforcement on the hysteretic behavior of flexural members subjected to repeated reversed loading. Specimens were tested by applying a constant axial load to the fixed column portion of the specimen and applying a cyclic shear load to the beam. The typical loading history of the beam was chosen to simulate the distortion which might take place at a typical connection in a ductile moment-resisting frame during a severe earthquake. Specimens were designed to have a variety of longitudinal beam reinforcement. They were tested using four different shear spans such that maximum shear stresses varied from 2 $\sqrt{f'_c}$ to 6 $\sqrt{f'_c}$. Half of the specimens contained beam web reinforcement as specified by the seismic provisions of the ACI building code 318-71 and half of the specimens contained two layers of intermediate longitudinal shear reinforcement in addition to the code-specified ties.

Several conclusions were drawn from the test results. The repeatability of member hysteretic behavior was related to maximum beam shear stress. Intermediate longitudinal shear reinforcement provided significant increases in member energy dissipation and repeatability of hysteretic response for beams with shear stresses between 3 $\sqrt{f'_c}$ and 6 $\sqrt{f'_c}$. Beams with shear stresses below this range performed satisfactorily without intermediate longitudinal shear reinforcement, and beams with shear stresses higher than 6 $\sqrt{f'_c}$ did not form totally satisfactorily, regardless of the type of shear reinforcement used. The buckling of compression reinforcement was found to be a significant factor in the loss of load-carrying capacity for more than half the specimens tested. It was found that stirrup size and strength were more important than stirrup spacing in preventing the buckling of longitudinal reinforcement.

● **6.2-110** Jimenez, R., White, R. N. and Gergely, P., **Bond and dowel capacities of reinforced concrete**, *Journal*

● *See **Preface**, page v, for availability of publications marked with dot.*

of the American Concrete Institute, **76**, *1*, Title No. 76-4, Jan. 1979, 73–92.

The interaction of bond and dowel effects in reinforced concrete is examined. Little interaction is found, and independent equations are proposed for the prediction of both dowel failures and bond failures of embedded bars or splices. Simple equations are derived from an assumed model of behavior. The concrete cover is found to be a major parameter. The effect of transverse reinforcement on bond capacity is included.

● **6.2-111** Kobatake, Y., **Study on shear strength of reinforced concrete walls subjected to biaxial bending-shear (Part 1: biaxial bending-shear tests)** (in Japanese), *Transactions of the Architectural Institute of Japan, 285,* Nov. 1979, 71–79.

In conjunction with the structural design of cast-in-situ diaphragm R/C walls constructed underground and along the periphery of buildings, biaxial bending shear tests of R/C wall specimens were performed. During the tests, the out-of-plane loads applied perpendicular to the wall surface to represent earth pressure were kept constant and the in-plane loads parallel to the wall surface to represent shear force caused by seismic loading were applied to failure. Influence of the out-of-plane load on the failure mode, deflection, and strength is discussed in this paper. In addition, characteristics of the specimens described above and those of specimens subjected to in-plane loads only are compared.

● **6.2-112** Tomii, M. and Yamakawa, T., **Stiffness matrix of two-story or two-bay duplex framed shear walls,** *Transactions of the Architectural Institute of Japan, 284,* Oct. 1979, 41–50.

In this paper, the authors derive the stiffness matrix of one-bay two-story or two-bay one-story duplex shear walls based on analytical solutions. The authors reported in an earlier paper on the stiffness matrix of single shear walls expressed in terms of the fundamental flexibility matrix, which can be given analytically. The plane stress analysis of symmetric rectangular single shear walls assumed to be isotropic elastic bodies was developed by analyzing each of the four fundamental components of the plane nodal external forces, moments, and distributed loads. This fundamental idea was applied to derive the stiffness matrix of single shear walls and is applied here for duplex shear walls which are symmetric with regard to their longitudinal and transversal center lines.

● **6.2-113** Komori, K., **Studies on strength and deflection of reinforced concrete slabs (Part 2: method to calculate strength and deflection of RC square cross-strip slab with edge beams)** (in Japanese), *Transactions of the Architectural Institute of Japan, 285,* Nov. 1979, 81–91.

In this paper, a method for calculating the strength and deflection of reinforced concrete square cross-strip slabs with edge beams is proposed. Two types of models are analyzed and experiments conducted to confirm the accuracy of the equation are discussed. It is found that the load-deflection curve of the slabs is calculated accurately by the equation.

● **6.2-114** Leombruni, P., Buyukozturk, O. and Connor, J. J., **Analysis of shear transfer in reinforced concrete with application to containment wall specimens,** *NUREG/CR-1085,* Div. of Reactor Safety Research, U. S. Nuclear Regulatory Commission, Washington, D. C., Oct. 1979, 214.

In this report, the shear transfer mechanism across continuous cracks penetrating through the thickness of a reinforced concrete element are investigated. The parameters influencing shear stiffness of the cracked sections are identified. Based on these parameters, a mathematical model is developed for prediction of shear stiffness. This model is used to evaluate the shear rigidity of orthogonally reinforced concrete panels exhibiting parallel or orthogonal through cracks. The model is applicable to biaxially tensioned wall specimens subjected to monotonically increasing tangential shear stress. For two test specimens, the shear rigidity as predicted by the proposed model is implemented in a finite element computer program. Three dimensional finite element analysis is performed for these specimens to study the behavior of a containment wall under biaxial tension and tangential shear loading. The influence of the crack patterns and their stiffness on shear deformation and reinforcement stresses in the specimen is evaluated. The proposed model and analysis procedure predict shear rigidities and structural responses consistent with the observed behavior of the test specimens.

● **6.2-115** Cooney, R. C. and Collins, M. J., **A wall bracing test and evaluation procedure,** *Technical Paper P21,* Building Research Assn. of New Zealand, Porirua, Jan. 1979, 17.

A wall bracing test and evaluation procedure is described and the reasons for its development and particular features outlined. For walls subjected to in-plane horizontal racking loads, the procedure leads to a rating value of bracing resistance in terms of "bracing units" which may be used to satisfy the provisions of NZS 3604:1978, Code of Practice for Light Timber Frame Buildings Not Requiring Specific Design. The procedure also allows for testing to confirm assumed permissible design loads for a particular construction to be used directly in engineering design. The procedure given is a modification of a test published earlier, the intention being to broaden the applicability of the earlier test and to relate it more closely to revised New Zealand standards on building design and construction.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● **6.2-116** Gill, W. D., **Ductility of rectangular reinforced concrete columns with axial load,** *Research Report 79-1,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1979, 136.

An experimental investigation is described of the post-elastic ductile behavior of reinforced concrete columns designed according to the requirements of the Draft New Zealand Code of Practice for the Design of Concrete Structures. Four full-sized column sections were built and subjected to a static cyclic lateral load sequence over a a range of axial compressive load levels. Ductility requirements of reinforced concrete columns are discussed and the results and analyses of experimental results are presented. Results are presented in the form of measured lateral load-displacement and moment-curvature relationships, curvature and longitudinal bar strain profiles, and transverse confining steel strains. Analysis of results includes the comparison of measured ductilities, plastic hinge lengths, concrete spalling and maximum compression strains, and stress-strain curves for confined concrete with those measurements obtained by existing analytical methods. Conclusions are made about the effectiveness of the confinement provided by the draft code recommendations.

● **6.2-117** Potangaroa, R. T., **Ductility of spirally reinforced concrete columns under seismic loading,** *Research Report 79-8,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1979, 116.

The project described in this report involved the design, construction, and testing under simulated seismic loading of five reinforced concrete columns. Each column had an octagonal cross section and contained longitudinal reinforcement and circular spiral reinforcement. The columns were tested under axial load and reversed flexure. Three of the test specimens were designed to the draft New Zealand Concrete Design Code DZ3101 using grade 275 spiral steel for axial load levels of $0.15f'_cA_g$, $0.35f'_cA_g$, and $0.55f'_cA_g$. Of the remaining two specimens, one was designed to DZ3101 using grade 380 spiral steel, and the other was designed to the New Zealand Ministry of Works design recommendations CDP810/A using grade 275 spiral steel; both were for an axial load level of $0.35f'_cA_g$. The test results gave information on the displacement and curvature ductility available from spirally reinforced concrete columns under reversed flexure for a range of axial load levels for spiral steel designed by the code procedures.

● **6.2-118** Rutenberg, A., **An accurate approximate formula for the natural frequencies of sandwich beams,** *Publication 241,* Faculty of Civil Engineering, Technion—Israel Inst. of Technology, Haifa, June 1978, 14.

The flexural beam approximation commonly used for evaluating the vibration frequencies of sandwich beams is shown to be of limited applicability. A formula proposed for evaluating the fundamental frequencies of cantilever sandwich beams is generalized for higher modes and other boundary conditions, and is shown to be in very good agreement with experimental and theoretical values.

● **6.2-119** Minakawa, Y., **Nonlinear vibrations of shells of revolution (nonlinear vibrations of shells of revolution—Part 2)** (in Japanese), *Transactions of the Architectural Institute of Japan, 282,* Aug. 1979, 107-112.

Some previously published reports of experiments on shells of revolution show that when shells are subjected to harmonic lateral loads the shells resonate in a lower region of frequency than that of the lowest natural frequency. In order to clarify the phenomenon, the author examines the nonlinear features of shells of revolution. It is shown that the types of nonlinear problems which may occur in certain types of shells of revolution under certain types of loads and the aforementioned phenomenon are caused by the accompanying nonlinear vibrations. This is ascertained by numerical analyses.

● **6.2-120** Tezduyar, H. T., Ariman, T. and Lee, L. H. N., **On seismically induced vibrations of pressure vessels with cutouts and cracks,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In this paper, the dynamic response of a finite circular cylindrical elastic shell representing a pressure vessel under periodic and seismic vibration is investigated. A more accurate dynamic form of Morley's equations is developed for a circular cylindrical shell. These governing equations are utilized to investigate the elastic behavior of a circular cylindrical vessel with an elliptical cutout or with an axial crack induced by the seismic load. The distribution of forces, moment stresses, corresponding stress concentration factors, and stress intensity factors around the crack tip are examined.

● **6.2-121** Reed, J. W., Webster, F. A. and Sun, P. C., **Alternative structural systems for high density fuel storage racks in existing facilities,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 4/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

High-density fuel storage systems (HDFSS) are required for existing nuclear power plants to replace present systems in order to provide temporary storage for spent nuclear fuel until technology has been developed to permanently store nuclear waste material. This paper discusses various structural systems for supporting spent fuel racks in existing facilities and presents their relative merits. A stiff support system was originally investigated to anchor fuel storage racks to spent fuel storage pools. The system

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

consisted of 20-in. high trusses beneath the racks which were supported directly on the floor slab and were laterally braced against the pool walls. Because of the large mass of the fuel relative to the stiffness properties of the trusses, the fundamental frequency of the system was found to be between 3 and 6 Hz, which corresponded closely to the fundamental frequency of the reactor building being investigated. A stiff support system was not found to be economically feasible. Flexible systems based on the concept of a pendulum were developed to decrease the frequency below the resonant peak of the reactor building. Short linkages with rounded ends supported in sockets which were attached to four corners of the racks and support frames were designed. Both vertical and slanted linkages were analyzed. Frequencies as low as 1 Hz were found to be possible and maximum deflections were calculated to be less than three inches. An alternative to the linkage scheme, but still based on the principles of a pendulum, consisted of four- to five-in. diameter balls in spherical dishes at each corner of the spent fuel rack. By selecting the radii of the dish supports, the properties of the pendulum can be controlled. Because of the high bearing stresses between the balls and supports, high-strength alloy materials are needed. A force limiting system was also investigated; this system controlled the amount of energy which could be transmitted by the pool slab to the storage rack. By allowing the rack to slide and tilt during seismic motion, the maximum transmitted force could be controlled by the coefficient of friction between the two sliding surfaces. The support system consisted of two matched surfaces constructed of a specially selected material. It was found, for a seismic floor motion with a 0.5 g peak floor acceleration, that the sliding displacements for coefficients of friction between 0.1 and 0.3 were less than one inch. Vertical uplift displacements at the corners of the rack were found to be less than one-tenth of an inch.

● **6.2-122** Yang, C. C. and Kraus, S., **Seismic analysis of the reactor assembly of a 1000 MWe-LMFBR pool reactor**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 12/4, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The seismic capability of the reactor assembly must be ensured in the conceptual design of a 1000 MWe pool-type LMFBR. The reactor assembly has to be designed to meet the Seismic Category I requirements. A preliminary seismic analysis was made to serve as a guide to this effect. A finite element model based on an axisymmetric formulation was established and analyses were conducted by means of the spectrum method. The response acceleration spectra at the reactor support for both a safe shutdown earthquake (SSE) and an operating basis earthquake (OBE) were obtained from a time history analysis of the reactor building which takes into account the coupling effect of the building and the reactor structure. A mass element representing a 12 x 12 mass matrix was used to take into account the hydrodynamic mass effect created by liquid sodium in annuli formed by cylindrical structures. The sloshing effect, within the hot pool, was incorporated into the model based on a simplified formulation of Housner's. The sloshing frequency was substantially lower (0.17 Hz) than the lowest natural frequency of vibration of the reactor assembly (4.77 Hz). The wave height was found to be approximately 4 ft under the SSE condition, neglecting the damping effect of the internal structures. Displacements and stresses were calculated for the major components of the reactor assembly. The functional requirements allow a 1.0 in. relative motion between the core and control rod drive systems for the vertical OBE and 2.0 in. for the vertical SSE. In any horizontal excitation, only 0.6 in. relative motion is allowed. These functional requirements are met. Stress results from the analysis based on the OBE were combined with stresses caused by loadings other than seismic and were shown to satisfy ASME code requirements. Stresses resulting from the SSE were checked against the requirements for the faulted condition. This preliminary seismic analysis, addressing various technical areas of importance, demonstrated that the 1000 MWe pool-type LMFBR design is a feasible design with a high potential of success while providing for good safety margins.

● **6.2-123** Kircher, C. A., Reed, J. W. and Hoggatt, D., **Seismic qualification of General Electric Test Reactor safety-related valves**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 13/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The purpose of this paper is to present the results of the experimental and analytical work conducted to seismically qualify safety-related valves located in the General Electric Test Reactor (GETR). The safety-related valves were investigated to determine their ability to withstand vibratory motion corresponding to a maximum postulated seismic event. Dynamic shaking table testing was performed to provide the primary basis for seismic qualification. Computer-based calculations were also performed to define the vibratory motion at the locations of the valves within the GETR reactor building. The characteristics of the vibratory motion were defined by several required response spectra which corresponded to the response spectra for the vibratory motion at each valve location in the reactor building.

Proof testing was used to qualify the safety-related valves for each required response spectrum corresponding to the maximum postulated seismic event. The proof testing included the following two procedures which increased the effectiveness of the experimental work: (1) the use of hardware-generated bandwidth-limited white noise to simulate seismic motion in each valve mounted to the shaking table and (2) the duplication of the pressure

● *See* ***Preface****, page v, for availability of publications marked with dot.*

environment for each valve before, during, and after the postulated event and the testing of each valve's ability to perform its specified safety-related function during the simulated seismic motion.

Dynamic testing was performed to determine the dynamic properties and to seismically qualify each safety-related valve. Accelerometers were used to record both shaking table excitation and equipment response. Transfer functions were calculated and used to determine the natural frequencies, mode shapes, and damping parameters. Test response spectra were calculated from the accelerations recorded in the shaking table and compared to the corresponding required response spectra to ensure that the vibratory motion produced by the shaking table conservatively enveloped the vibratory motion resulting from the maximum postulated earthquake.

● **6.2-124** Suzuki, K. et al., **Experimental and analytical studies on aseismic design of ventilation ducts,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/9, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

For the seismic-resistant design of ventilation ducts, the most widely used and convenient practice is to idealize the duct as a simple beam model and to compute the maximum support spacing that would provide sufficient rigidity. However, little practical data are available on the precise stiffness of thin-walled ducts on which to base the accurate prediction of dynamic properties. In this paper, an experimental study that included vibration and static load tests of two full-scale duct models is described, and a comparison of experimental and analytical results of the dynamic properties, the deflections, and the stress distributions is discussed. Also, the mode of failure of the ducts resulting from a vertically applied static load with a negative internal pressure is observed. The results derived from this study are as follows: (1) For a circular duct, the measured fundamental frequency is in good agreement with the analytical prediction assuming that the entire cross section contributes to the stiffness of the duct. (2) For a rectangular duct, the cross section of the flanges scarcely contributes to the stiffness of the duct. (3) For a circular duct, the measured load-deflection relationship and the buckling load are in good agreement with the analytical prediction calculated by means of the finite element method and Donnell's shell theory. (4) The critical damping of both models is approximately 2%.

● **6.2-125** Chandrasekaran, A. R., **Influence of different types of mass matrices on vibration characteristics of two dimensional problems,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-37-42.

In the evaluation of the dynamic characteristics of systems, the mass matrix is invariably assumed to be diagonal. Some of the methods used for lumping of the coefficients are described in this paper. The coefficients of the matrix are sometimes evaluated by intuition and physical lumping. In finite element analysis, equivalent nodal forces resulting from gravity-type loading are sometimes used to obtain these coefficients. Special techniques are also used to obtain a diagonal matrix from the coefficients of a consistent mass matrix. Also examined in this paper are the influence of different types of mass matrices on the vibrational characteristics of two-dimensional structures. For these elements, new shape functions which retain the basic characteristics of existing isoparametric elements have been retained, and several choices are available for improving the elements without adding any surplus variables or interior nodes. The effect of using different sets of shape functions, one for a stiffness matrix and another for a mass matrix, have been examined. It is concluded that as far as a stiffness matrix is concerned the serendipity-type shape functions are most ideal. However, for mass matrices, the type of shape functions used is not critical and an alternate set of shape functions could be used with advantage in some applications.

● **6.2-126** Filippi, G. et al., **Seismic and accident analysis of electrical machinery,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/11, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Typical electrical machine models are described, and the results of analyses conducted to determine eigenfrequencies and eigenmodes are presented. The analysis shows that careful detailing in such models is essential because, while a structure as a whole is very rigid and does not present particular problems, some local effects have sometimes been found. The use of a version of the SAP IV computer code permits an efficient approach to the problem. The demand for displacement control forces the designer to use very stiff structures so that no problem should arise from the low-frequency excitation of the earthquake, even if structural resistance could have been guaranteed by using a simpler structural solution. These analyses have shown that, while the original machines (designed for conventional service) are generally sound and useful for more sophisticated functions, some modifications have been found necessary. The typical pattern of these modifications is shown and examples of corrective measures are presented and discussed.

For electrical machines to be used in fast breeder reactors, thermal loads and such accidents as explosions or other dynamic loads have to be considered. Some examples are given.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.2-127** Muto, K., Motohashi, S. and Kuroda, K., **Two-dimensional vibration test and its simulation analysis for a horizontal slice model of HTGR core,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/2, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Forced vibration test and a simulation analysis were conducted of a two-dimensional horizontal slice model of a high-temperature gas-cooled reactor core subsequent to a vertical slice model test. The purpose was to clarify such dynamic properties as resonant characteristics and vibration modes of the core, lumping phenomena of the blocks, and distribution of reflector reactions. During the forced vibration tests when sinusoidal waves were used as input, resonant phenomena as seen in the vertical slice test could not be observed. The block behaviors are greatly influenced by the input displacement irrespective of input frequency and g-level. When random input was used, collision between the end block and the reflector occurred about four times during three seconds of the main shock (about seven seconds in the actual core). The distributed pattern of the reflector reaction is similar to the case of sinusoidal wave input. The reflector reactions increase with an increase in input g-level. A computer code COLLAN 2-H was developed to theoretically simulate the test results. The analytical results coincide fairly well with the experimental results.

● **6.2-128** Shiraki, K. et al., **Vibrational characteristics of primary reactor coolant system,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/8, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Shaking table tests were conducted on a 1/4-scale plastic model of a primary reactor coolant system loop to determine the dynamic properties and seismic response of the system. The response of the loop was calculated using the modal analysis method, and the experimental results and analytical results compared.

● **6.2-129** Patel, Y. A., **An interior collocation method for vibration of a rectangular plate carrying attached mass,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 10/2, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A new, simplified method is developed for computing the fundamental frequency of a coupled plate/mass system representative of a piece of Category I equipment and its foundation. This approach is based on the interior collocation method for vibration analysis. The differential equation for small free oscillations of the homogeneous flat plate of uniform thickness with no constraints other than at the boundaries is given. The equation is modified for a concentrated mass at an arbitrary location and a solution is developed for the modified fundamental frequency of the assembly. The modification technique is quite general and can be used either for a single mass or any number of masses at arbitrary locations. Results from this new method are compared with the earlier solutions obtained by other investigators using the Lagrange equation and the finite Fourier transfer technique with a dirac function. Good agreement is obtained between this method and the previous solutions. This method is of special use in the preliminary seismic analysis of Category I structures in nuclear power plants.

● **6.2-130** Takahashi, K., **A method of stability analysis for non-linear vibration of beams,** *Journal of Sound and Vibration,* **67,** *1,* Nov. 8, 1979, 43-54.

In this paper, a method of stability analysis for the large amplitude, steady state response of a nonlinear beam under periodic excitation is presented. The stability problem is investigated by studying the behavior of a small perturbation of the steady state response which results in a coupled Hill-type equation. The problem is transformed by the harmonic balance method into an eigenvalue problem of a non-symmetric matrix. The effectiveness and the accuracy of the proposed method for a Mathieu equation are examined and the application to the stability analysis of the nonlinear vibrations of a beam is presented.

● **6.2-131** Ioannides, E. and Grootenhuis, P., **A finite element analysis of the harmonic response of damped three-layer plates,** *Journal of Sound and Vibration,* **67,** *2,* Nov. 22, 1979, 203-218.

Solutions have been obtained for the vibration response under harmonic excitation of three-layer plates with a constrained viscoelastic layer (e.g., plates with two metallic outer layers and a viscoelastic core) by means of a finite element method. Damping has been introduced by replacing the real modulus of the viscoelastic material by a complex equivalent which accounts for the phase difference between strain and stress. Triangular finite elements were used with different numbers of degrees-of-freedom and the dynamic stiffness of the overall structure was calculated. The present method allows for the nonlinear stress-strain behavior of the viscoelastic material, the effects of the rotatory inertia, and the extension within the viscoelastic core. In addition, the use of triangular elements allows for a great variety of shapes and boundary conditions. The finite element computation has been verified by comparison with experimental results for circular three-layer plates and for sandwich beams.

● **6.2-132** Bucco, D., Mazumdar, J. and Sved, G., **Vibration analysis of plates of arbitrary shape—a new approach,** *Journal of Sound and Vibration,* **67,** 2, Nov. 22, 1979, 253-262.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

The so-called finite strip method combined with the deflection contour method has proved highly successful in the analysis of bending of thin elastic plates of arbitrary shape. In this paper, the same technique is used to obtain the fundamental frequency of plates of arbitrary shape. The method of approach is much simpler than the conventional finite element method since it requires less programming effort and a reduction in both memory space and time on the computer. Several representative plate problems of irregular boundaries are treated by the proposed method. For all cases, comparison of the results are made with other known solutions and the agreement appears to be excellent.

● **6.2-133** Khurasia, H. B. and Rawtani, S., **Vibration analysis of circular segment shaped plates,** *Journal of Sound and Vibration,* **67,** *3,* Dec. 8, 1979, 307-313.

Circular-segment-shaped plates are analyzed to determine their natural frequencies and mode shapes of vibration. The analysis is based on the finite element approach. The curved sided triangular plate bending element is used for solving the problem. The effect of variation of the size of the plate on the vibrational characteristics is studied and several important conclusions are made.

● **6.2-134** Chang, S.-D. and Greif, R., **Vibrations of segmented cylindrical shells by a Fourier series component mode method,** *Journal of Sound and Vibration,* **67,** *3,* Dec. 8, 1979, 315-328.

The vibrations of a multi-segment cylindrical shell with a common mean radius are studied. The shell is uniform for any segment but the material and geometric properties may vary from segment to segment. The solution is based on the component mode method coupled with Fourier series and Lagrangian multipliers. It is shown that a single segment shell with boundary conditions of free support without tangential constraint is sufficient for an arbitrary shell with arbitrary boundary conditions. Results are presented for simply supported shells and clamped-free shells for two segments with different lengths and thicknesses.

● **6.2-135** Irie, T., Yamada, G. and Ito, F., **Free vibration of polar-orthotropic sector plates,** *Journal of Sound and Vibration,* **67,** *1,* Nov. 8, 1979, 89-100.

The free vibration of ring-shaped, polar-orthotropic sector plates is analyzed by the Ritz method using a spline function as an admissible function for the deflection of the plates. For this purpose, the transverse deflection of a sector plate is written in a series of the products of the deflection function of a sectorial beam and that of a circular beam satisfying the boundary conditions. The deflection function of the sectorial beam is approximately expressed by a quintic spline function, which satisfies the equation of flexural vibration of the beam at each point dividing the beam into small elements. The frequency equation of the plate is derived by means of the conditions for a stationary value of the Lagrangian. The present method is applied to ring-shaped, polar-orthotropic sector plates with some combination of boundary conditions, and the natural frequencies and the mode shapes are calculated numerically up to higher modes. This method is very effective for the study of vibration problems of variously shaped anisotropic plates including these sector plates.

● **6.2-136** Chonan, S., **Resonance frequencies and mode shapes of elastically restrained, prestressed annular plates attached together by flexible cores,** *Journal of Sound and Vibration,* **67,** *4,* Dec. 22, 1979, 487-500.

The free vibrations of annular plates attached together by flexible cores are studied analytically. Both axisymmetric and nonaxisymmetric vibrations are considered. The plates are elastically constrained against rotation at the inner and outer edges. At the same time, the plates are subjected to initial radial tensions. A detailed analysis is worked out for systems consisting of two, three, four, and five identical plates with identical boundary conditions and a uniform radial tension. General frequency equations and mode shapes are developed. The first nine eigenvalues are calculated for a plate system having identically constrained inside and outside edges and are tabulated as functions of the initial tension parameter, the elastic edge constraint parameter, and the ratio of inner to outer radius. The orthogonality property of the mode function is also discussed.

● **6.2-137** Varadan, T. K. and Pandalai, K. A. V., **Large amplitude flexural vibration of eccentrically stiffened plates,** *Journal of Sound and Vibration,* **67,** *3,* Dec. 8, 1979, 329-340.

The large amplitude free flexural vibrations of thin, orthotropic, eccentrically and lightly stiffened elastic rectangular plates are investigated. Clamped boundary conditions with movable in-plane edge conditions are assumed. A simple modal form of one-term transverse displacement is used and in-plane displacements are made to satisfy the in-plane equilibrium equations. By using Lagrange's equation, the modal equations for the nonlinear free vibration of stiffened plates are obtained for the cases when the stiffeners are assumed to be over the entire surface of the plate, and when the stiffeners are located at finite intervals. Numerical results are obtained for various possibilities of stiffening and for different aspect ratios of the plate. By particularizing the problem to different known cases, the results obtained are compared with available analytical and experimental results, and the agreement is found to be good.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.2-138** Mukhopadhyay, M., **Free vibration of rectangular plates with edges having different degrees of rotational restraint,** *Journal of Sound and Vibration,* **67,** *4,* Dec. 22, 1979, 459-468.

A numerical method developed by the author has been used as a basis for determining natural frequencies of rectangular plates possessing different degrees of elastic restraints along the edges. The basic functions satisfying the boundary conditions along two opposite edges for such cases have been derived. Comparison of results with other methods indicates excellent accuracy. New results are presented.

● **6.2-139** Yang, T. Y. and Baig, M. I., **Seismic analyses of fossil-fuel boiler structures,** *Journal of the Structural Division, ASCE,* **105,** *ST12,* Proc. Paper 15063, Dec. 1979, 2511-2528.

A seismic analysis has been performed for 600-Mw and 1200-Mw steam generators and their supporting structures using realistic three-dimensional finite element models. The 600-Mw power plant is located in seismic Zone III while the 1200-Mw plant is located in Zone I. Because of the greater possibility of an earthquake in Zone III, the power plant in that zone was designed according to the specifications of the Uniform Building Code. Each suspended boiler is analyzed by means of an analytical model as well as by a finite element model with four hanger rods. For each plant, twelve natural frequencies and associated mode shapes of the combined boiler and structural finite element model have been obtained. For the 600-Mw boiler structure, the spectra of modal responses of the relative displacements of the joints and the axial stresses in the structural members are obtained based on the 1940 El Centro earthquake. It is found that the axial stresses exceed the yield stress and the Euler buckling stresses in a minority of the members. Small damping coefficients significantly reduce the response displacements.

● **6.2-140** Basu, A. K. et al., **Dynamic characteristics of coupled shear walls,** *Journal of the Structural Division, ASCE,* **105,** *ST8,* Proc. Paper 14783, Aug. 1979, 1637-1652.

The first three natural frequencies and the corresponding mode shapes for fixed-base coupled shear walls are presented. The wall is modeled as a continuum of uniform properties and the resulting sixth-order homogeneous differential equation in terms of lateral displacement is solved exactly using appropriate numerical methods. The results are presented for various combinations of the two nondimensional parameters which between them incorporate all the geometric and material properties of the wall system. The mode shapes are presented in terms of the first three normal modes of a uniform slender cantilever. The nondimensional base shears appropriate for the response spectrum analysis of the walls under seismic loading are also given for the three modes and for the various combinations of the wall parameters referred to earlier. The results show that the coupled wall mode shapes cannot be adequately approximated by the corresponding shapes for a slender cantilever.

● **6.2-141** Shibata, H. et al., **Investigation on the design damping values for seismic analysis of nuclear power plant piping systems,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/3, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In this paper, design damping values used in Japan for piping systems are re-evaluated, and the mechanisms of damping for such systems are clarified. As a first step, experimental data obtained during pre-operating tests of piping systems were collected from 18 light water reactor power plants in Japan. These damping values were measured for various piping sizes. The pre-operation data tend to confirm the design basis values. Using scatter diagrams, the data were analyzed with regard to deflection amplitude, diameters, frequencies, and other factors which were considered to contribute to the damping characteristics. Because of the strong variations concerning these factors, no conclusions could be reached.

Statistical analyses were applied to evaluate the correlation between the measured damping values and the damping influence factors. It was clarified that some factors, such as type of support, frequency, and presence of fluid in the pipes, show a correlation with damping. However, it was not possible to make a definite prediction of the design damping ratio of piping systems only based on these data.

By means of a multiple regression analysis, it was clarified that the high damping values could be estimated with proper reliability for some types of piping systems classified by pipe size, supporting conditions, etc. This indicates that reliable evaluations can be made for other types by standardizing the pre-operating test and measuring method and by increasing the amount of comparative data by means of systematic vibration tests.

● **6.2-142** Elishakoff, I. and Sternberg, A., **Eigenfrequencies of continuous plates with arbitrary number of equal spans,** *Journal of Applied Mechanics, ASME,* **46,** *3,* Sept. 1979, 656-662.

An approximate analytical technique is developed for determination of the eigenfrequencies of rectangular isotropic plates continuous over rigid supports at regular intervals with an arbitrary number of spans. All possible

● *See **Preface**, page v, for availability of publications marked with dot.*

combinations of simple support and clamping at the edges are considered. The solution is obtained by means of the modified Bolotin method, which involves solution of two problems of the Voigt-Levy type in conjunction with a postulated eigenfrequency/wave-number relationship. These auxiliary problems yield a pair of transcendental equations in the unknown wave numbers. The number of spans figures explicitly in one of the transcendental equations, so that numerical complexity does not increase with the number of spans. It is shown that the number of eigenfrequencies associated with a given pair of mode numbers equals that of the spans. The essential advantage of the proposed method is the possibility of finding the eigenfrequencies for any prescribed pair of mode numbers. Moreover, for plates simply supported at two opposite edges and continuous over rigid supports perpendicular to those edges, the result is identical with the exact solution.

● **6.2-143** Manrique, M. A., Bertero, V. V. and Popov, E. P., **Mechanical behavior of lightweight concrete confined by different types of lateral reinforcement,** *UCB/EERC-79/05,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 129. (NTIS Accession No. PB 301 114)

Results are reported of an experimental study carried out at the Univ. of California at Berkeley as part of an ongoing research program to evaluate the behavior of lightweight concrete. The study focuses on the behavior of confined lightweight concrete when subjected to axial, monotonic loading. The effect on confined concrete of the following parameters was considered: (a) concrete cover, (b) longitudinal reinforcement, and (c) lateral reinforcement arrangement. Thirty confined and unconfined specimens were tested. The effect of the mentioned parameters were evaluated and the experimental results compared with the results of a similar investigation carried out on normal weight concrete. Current code-implied values for confinement effectiveness coefficients and the experimentally obtained values are compared and the consequences of the differences obtained are discussed. An analytical stress-strain relationship for longitudinally reinforced confined lightweight concrete is presented which considers the effect of increase in strength and strain at maximum stress resulting from confinement as well as the effect of the different types of lateral reinforcement and the effect of the longitudinal reinforcement on the descending branch of the stress-strain relationship. Practical design implications of the study are presented. Discussed are the effects that the avoidance of buckling of the longitudinal reinforcement by means of close spacing of the lateral reinforcement would have on the ductility of the concrete and on the axial load-moment interaction diagrams obtained from current ACI assumptions of the material properties of both concrete and steel.

● **6.2-144** Tarpy, Jr., T. S., McCreless, C. S. and Lindsey, S. D., **An economic approach for seismic design: research to practice,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 408-418. (For a full bibliographic citation, see Abstract No. 1.2-21.)

This paper presents the results of a full-scale experimental test program for determining the feasibility of using interior framed wall partitions as vertical diaphragms to resist lateral forces caused by seismic and hurricane loadings. The wall construction consists of gypsum wallboard panels attached to light gage structural steel studs and is representative of the type of construction commonly used for lowrise structures. Design formulas are presented based upon the test results.

● **6.2-145** Sato, H., **Free vibration of clamped square plates with multi-holes** (in Japanese), *Memoirs of the Faculty of Technology, Kanazawa University,* **12,** 2, Oct. 1979, 79-85.

Natural frequencies and modes of clamped square plates with a multiple number of openings are investigated theoretically and experimentally. The number of square or circular openings in each plate vary from one to twenty-five. The theoretical analysis for plates with square openings is done by using the finite element method. It is found that plates with five or more openings have almost the same natural frequencies, regardless of the shape or number of the openings. These frequencies are rather low or nearly equal and the mode shapes are almost the same as the shapes for plates with no openings. Agreement between calculated and experimental results for the plates with square openings is generally good.

● **6.2-146** Seya, Y. and Matsui, G., **Study of stress and displacement of shear wall with opening** (in Japanese), *Transactions of the Architectural Institute of Japan, 286,* Dec. 1979, 45-53.

It is well known that stress concentration occurs around wall openings when they are subjected to shear forces. Until now, almost all investigations have dealt with the normal stress concentration around or at the corners of the openings. However, the increase in shear stresses a slight distance from the openings has not been carefully examined. Model tests of reinforced concrete walls with openings subjected to shear forces show that large cracks occur in zones where shear stresses increase, and that these cracks cause failure. In this paper, the authors study shear walls having square or rectangular openings by means of two-dimensional analyses and the theory of elasticity. The accuracy of the results is examined by comparison with the results of photoelastic experiments. The following results are obtained. In order to design a shear wall with an opening, not only the normal stress concentration immediately surrounding the opening, but also the increase in

● *See **Preface,** page v, for availability of publications marked with dot.*

shear stresses a slight distance from the opening need to be considered. The maximum ratio of the shear stress to the mean shear stress in a framed wall with a square opening is 1.4.

6.2-147 Polyakov, S. V. et al., **Strength of seismically loaded columns in inclined cross sections** (Prochnost' kolonn po naklonnym secheniyam pri deistvii seismicheskikh nagruzok, in Russian), *Beton i zhelezobeton, 6,* June 1979, 13-15.

Results are presented of a study of the strength of columns acted upon by longitudinal compressive and transverse forces in inclined cross sections through the columns during nonrecurrent unilateral and recurrent alternating loading. The results of this research and an analysis of previously published data are used to suggest recommendations for the seismic design of transverse column reinforcements.

6.2-148 Kumpyak, O. G. and Belobrov, I. K., **Redistribution of forces in dynamic loading** (Pereraspredelenie usilii pri dinamicheskikh nagruzheniyakh, in Russian), *Beton i zhelezobeton, 7,* July 1979, 7-9.

Results are presented of experimental studies carried out on statically indeterminate reinforced concrete beams subjected to short-term dynamic loading. The data obtained (redistribution of forces, limiting deflections) are useful for improved design of structures intended to withstand seismic, explosive, and similar loads.

6.2-149 Kotov, Yu. I., **Strain in heavy concrete and in silicate under near-seismic loads** (Deformatsiya tyazhelogo betona i gazosilikata pri nagruzkakh, blizkikh k seismicheskim, in Russian), *Beton i zhelezobeton, 6,* June 1979, 20-22.

Strain experienced by grade M 200 heavy concrete and by grade M 50 silicate fabricated from dune sands is examined, with emphasis on repeated dynamic loads closely simulating seismic loading. Data are reported on changes in the relative levels of total, elastic, and residual strain.

6.2-150 Zhunusov, T. Zh. and Bespaev, A. A., **Strain in impulsively loaded flexible structural members** (Rabota izgibaemykh elementov pri impul'sivnykh vozdeistviyakh, in Russian), *Beton i zhelezobeton, 6,* June 1979, 15-17.

The paper discusses the response of flexible reinforced concrete structural members subjected to impulse loads. The effects of reinforcement ratio, grade of steel, and prestressing are demonstrated. An analysis of strength, dynamic coefficients, damping, and energy dissipation leads to proposals for improved designs employing high-strength steel rods.

● **6.2-151** Vargas Neumann, J., **Shear strength of adobe with different kinds of mortar** (Albanileria de adobe con variaciones de mortero, in Spanish), *DI-79-02,* Dept. de Ingenieria, Pontificia Univ. Catolica del Peru [Lima], Apr. 1979, 19.

This report analyzes the shear strength of adobe walls constructed with different types of mortar (gypsum, lime, and cement).

● **6.2-152** Collington, D. J. and Brebbia, C. A., **Dynamics and stability of shells of revolution,** *Environmental Forces on Engineering Structures,* 397-413. (For a full bibliographic citation, see Abstract No. 1.2-28.)

The present study represents an attempt to quantify the relationship between free vibration frequencies and bifurcation loads for thin shells. The dynamic equilibrium equations for a system are derived from a generalized form of Hamilton's principle. These equations are solved by a finite element discretization which uses a set of displacement expansions that are rapidly convergent but not fully compatible. The shell strain-displacement relationships are based on the work of Sanders and are valid for linear and geometrically nonlinear behavior. Discretization of the Lagrange equations produces a symmetric system in which dynamic, viscous, and stiffness (linear and nonlinear) forces are taken into consideration. Specializing these equations leads to the normal form of the free vibration equation or to the equation for static bifurcation from a linear fundamental path. In addition, they contain the information required for static bifurcation from a nonlinear fundamental path, and the dynamic stability equations of Bolotin. Examples are presented which illustrate the application of these equations to some practical problems.

● **6.2-153** Delpak, R., **Determination of natural frequencies of the thin rotational shells by finite element method,** *Environmental Forces on Engineering Structures,* 371-395. (For a full bibliographic citation, see Abstract No. 1.2-28.)

A curved parametric element, capable of giving the natural unforced and undamped frequencies of thin rotational shells, has been developed. The new formulation possesses a number of interesting features including true nodal conformity, genuine curved generator, optional number of degrees-of-freedom and variable thickness. The nature of the displacements and the generation of the stiffness and the mass matrices are outlined in the text. Finally, the accuracy of the present formulation is examined by considering a selected number of well-known examples.

● **6.2-154** Wilson, J. C., **Earthquake floor response and fatigue of equipment in multi-storey structures,** *Environmental Forces on Engineering Structures,* 181-196. (For a full bibliographic citation, see Abstract No. 1.2-28.)

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

This paper examines the seismic response of multistory structures and their equipment installations and attempts to characterize some parameters of equipment response which prove useful in laboratory dynamic testing. Mathematical models of several typical structures are subjected to a 30-second earthquake excitation and the seismic response at the top floor of each building is evaluated using the modal superposition technique. This response is then used as an input to a single-degree-of-freedom representation of an equipment component located on the top floor, and its quasi-harmonic response and low-cycle fatigue are examined. The paper closes with a discussion of test methods, which can incorporate characteristics of the previous analysis to test the functional capability (seismic qualification) of electrical and mechanical equipment exposed to an earthquake environment.

6.2-155 Mizukami, T. and Nishioka, T., **A vibration analysis on folded plate structures by Legendre polynomials,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 48-51. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 277,* Sept. 1978, 1-14.)

Many analytical and approximate theories of the vibration of plates and folded plate structures have been published. These can be classified briefly into Fourier transform and finite element methods. The purpose of this paper is to present an analytical theory based on the weighted residual method by assuming the Legendre polynomials to be a displacement function without dividing a continuous plate into discrete elements. The advantage of this theory is that it provides infinite degrees-of-freedom for the displacement function because of the use of a convergent orthogonal function, which permits an easy solution to the eigenvalue problem.

6.2-156 Nishimura, T. and Miki, C., **Strain controlled low cycle fatigue behavior of structural steels,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 91-94. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 279,* Nov. 1978, 29-44.)

In this paper, five structural steels are tested under strain-controlled conditions and the effects are discussed of the type of steel and the mean strain on the following parameters: (1) the characteristic of crack initiation, (2) strain-amplitude-versus-life diagram, (3) cyclic hardening and softening behavior and cyclic stress strain curve, (4) the method for obtaining an approximate cyclic stress strain curve from one specimen, and (5) changes in tensile properties as a result of strain cycling.

● **6.2-157** Ahmadi, G., **Earthquake response of nonlinear plates,** *Nuclear Engineering and Design,* **54,** *3,* Nov. 1979, 407-417.

The finite amplitude vibration of a plate subjected to earthquake support motion is considered. Several bounds on the maximum responses of the plate are established which are based on the knowledge of the response spectra of the seismic motion. The stochastic models of the earthquake ground motion are briefly discussed. The single mode of vibration of the plate is considered and a perturbation series expansion is developed for the vibration amplitude. Mean square responses of the plate are calculated for stationary and nonstationary seismic excitations. It is observed that the variance of the deflection field of the nonlinear plate is less than that of the corresponding linear one. The reliability of design is also considered and the probability of no barrier being crossed is briefly discussed.

● **6.2-158** ACI Committee 207, **Practices for evaluation of concrete in existing massive structures for service conditions,** *Concrete International,* **1,** *3,* Mar. 1979, 47-61.

Current methods available for evaluating physical properties of concrete in existing structures to determine its capability of performing satisfactorily under service conditions are identified and discussed. Although general knowledge of the structural design criteria used for the principal structures of a project is essential to determine satisfactory procedures and locations for evaluation of the concrete physical properties, analysis for the purpose of determining structural capability is not within the scope of this report. The report recommends project design, operation and maintenance records and in-service inspection data to be reviewed. Existing methods of making condition surveys and nondestructive tests are reviewed; destructive phenomena are identified; methods for evaluation of test and survey data are presented; and, finally, preparation of the final report is discussed.

6.2-159 Nagaya, K., **Vibration of a plate having a circular inside edge and a cornered outside edge consisting of arcs,** *Journal of the Acoustical Society of America,* **66,** *6,* Dec. 1979, 1788-1794.

This paper is concerned with the transverse vibration of a thin plate having a circular inside edge and a cornered outside edge consisting of arcs. The classical plate theory is applied and the eigenvalue problem of the plate is solved by use of the exact solution of the equation of motion which satisfies the inner boundary conditions. The boundary conditions at the outer edge are satisfied by means of the Fourier expansion method. Numerical calculations are carried out for a plate having a clamped circular inside edge and a free outer edge consisting of three arcs. Experimental results are also given as an additional check of this analysis.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

6.2-160 Nagaya, K., **On the analysis of the doubly connected problem of vibrating polygonal plates,** *Journal of the Acoustical Society of America,* **66**, *6*, Dec. 1979, 1795–1800.

In this paper, a method is presented for solving vibration problems of thin polygonal plates with circular inside edges. The frequency equations of the polygonal plates are given for various combinations of outer and inner boundary conditions. Numerical calculations are carried out for cases of triangular, square, pentagonal, and hexagonal plates.

6.3 Dynamic Properties of Linear Structures

6.3-1 Peleg, K., **Frequency response of non-linear single degree-of-freedom systems,** *International Journal of Mechanical Sciences,* **21**, 2, 1979, 75–84.

Simple linear Kelvin or Maxwell models cannot adequately predict the response of many practical systems to vibration excitation. A more realistic model, consisting of a mass between two preloaded nonlinear cubic elasticity springs and restrained by a Coulomb and viscous damper, is proposed. A harmonic motion solution, satisfying on the average the nonlinear differential equation of motion of the model, is developed and used to obtain equations for frequency response curves. Expressions for relative and absolute transmissibility and their values at resonance are developed; these values can be properly reduced to the respective exact expressions of a Kelvin model and a frictionally damped linear spring. Although the model is intended mainly for quantitative design in packaging engineering problems, it is suitable for studying general vibration isolation problems as well.

● **6.3-2** Williams, F. W., **Simple buckling and vibration analyses of beam or spring connected structures,** *Journal of Sound and Vibration,* **62**, *4*, Feb. 22, 1979, 481–491.

The problem considered is the buckling or vibration of a system of n columns, or n general structures, which are suitably related to each other and are connected by sets of springs, or inextensible beams, which are also suitably related to each other. It is shown that all the critical loads, natural frequencies, and modes which are required in buckling and vibration problems can be found from n substitute systems, each consisting of one column or structure and a single set of springs. The derivation of these substitute systems involves the solution of a very simple linear eigenvalue problem of order n, which has closed-form solutions for several of the special cases considered. The reduction of the original system to n substitute systems has been adapted to permit the use of design procedures that avoid a complete analysis of each trial design.

● **6.3-3** Tomlinson, G. R. and Hibbert, J. H., **Identification of the dynamic characteristics of a structure with coulomb friction,** *Journal of Sound and Vibration,* **64**, 2, May 22, 1979, 233–242.

The effect of coulomb friction on the Kennedy and Pancu vector plot of a single degree-of-freedom system is analyzed using the method of harmonic balance. It is shown that the resulting diagram no longer conforms to a locus of a circle in the resonant region, which restricts the usual methods of analysis. A technique, based upon the in-phase and quadrature power dissipated when exciting a normal mode, is presented which allows the magnitude of the nonlinear friction force and the hysteretic damping constant to be evaluated. The technique is also applied to systems having several degrees-of-freedom, and it is shown that it is possible to identify the characteristics of a single nonlinear coulomb device situated within a structure. In the case of more than one device, the technique has some restrictions. The theoretical results are compared with experimental data from a structure containing a nonlinear coulomb device.

● **6.3-4** Hundal, M. S., **Response of a base excited system with coulomb and viscous friction,** *Journal of Sound and Vibration,* **64**, *3*, June 8, 1979, 371–378.

The response of a single degree-of-freedom spring-mass system with viscous and coulomb friction subjected to harmonic base excitation is determined. Closed-form analytical solutions of the equation of motion are found for two cases: (1) continuous motion of the mass, and (2) motion of the mass with two stops per cycle. Results are presented in nondimensional form as magnification factors versus frequency ratios for various values of viscous and coulomb friction parameters.

● **6.3-5** Cheung, Y. K. and Swaddiwudhipong, S., **Free vibration of frame shear wall structures on flexible foundations,** *Earthquake Engineering & Structural Dynamics,* **7**, *4*, July-Aug. 1979, 355–367.

The finite strip method is used to study the effect of an elastic foundation on the natural frequencies of a coupled frame–shear wall structure. The solid wall in the structure is divided into several strip elements; the column is treated as a line element; and the effect of the connecting beams is dealt with by use of compatibility matrices which transfer the structural properties of the beams to the adjacent strip or line elements. The comparison functions which satisfy the boundary conditions of being free at the top and being spring-supported at the bottom are used for the displacement field in the longitudinal direction. A series of numerical examples shows the accuracy and applicability of the proposed method.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● 6.3-6 Thomas, D. L., **Dynamics of rotationally periodic structures,** *International Journal for Numerical Methods in Engineering,* **14,** *1,* 1979, 81–102.

This paper considers the finite element analysis of the free undamped and the forced damped vibrations of rotationally periodic structures. Associated with every natural frequency (except for those for which the deflection is the same at corresponding points on every substructure), there are a pair of orthogonal mode shapes, with eigenvectors. The complex vector is also an eigenvector of the equations of motion and represents a rotating normal mode. The deflection of one substructure has the same amplitude as, and a constant phase difference from, the deflection of the preceding substructure. It is therefore possible to analyze the complete structure by considering only one substructure and applying appropriate complex constraints at its boundary with the following substructure so as to impose this phase difference. The method has been implemented in a computer program and is illustrated by analyses of an alternator end winding, a cooling tower with legs, and a wheel of turbine blades.

For forced vibration, it is shown that any arbitrary oscillatory force can be decomposed into a series of rotating forces. For any one of these rotating components, there is a fixed relationship between the amplitude and phase of the force acting on one substructure and that acting on an adjoining substructure. This relationship, which does not involve any approximation, can be used to enable a series of calculations of the response of one substructure to be performed instead of for the whole structure. A series of calculations on an individual substructure normally requires much less computer time and storage than a single calculation on the complete structure.

● 6.3-7 Kirillov, A. P., **The main problems involved in the earthquake-resistance of nuclear power stations,** *Engineering Design for Earthquake Environments,* Paper No. C170/78, 11–15. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The special distinguishing feature of nuclear power plant design for seismic areas is the need to conduct a dynamic analysis of the main systems that determine the radiological integrity of the plant. This requirement is based not only on the need to estimate strength and distortion of structural and technological systems but also to ensure the functioning of control systems. A dynamic analysis requires that the seismic influence be specified in the form of an accelerogram. Current techniques for establishing the dynamic characteristics of the ground at a particular site are not satisfactory; therefore, analog or artificial accelerograms must be used. At the present time in the U.S.S.R., there are a number of proposals, based on improved methods, for establishing an accelerogram to be used in connection with nuclear power plant construction in seismic areas.

The simultaneous requirements of reliability and efficiency for nuclear power plants built in seismic areas necessitates that all systems be placed into security categories. This procedure permits the separate consideration of the structure, equipment (including piping systems, reactor, and steam generator), and the electrical control and operating systems. The dynamic analysis of buildings permits estimation of their stress states and the floor vibration characteristics for places where equipment and electrical and electronic systems will be located. Equipment and control and operating systems necessary for shutting down and cooling the reactor must not fail and must continue to operate under floor vibrations. The strength analysis of systems can be carried out using floor response spectra while the reliability of control and operating systems can be guaranteed by means of dynamic tests.

● 6.3-8 Abdel-Ghaffar, A. M., **Free torsional vibrations of suspension bridges,** *Journal of the Structural Division, ASCE,* **105,** *ST4,* Proc. Paper 14535, Apr. 1979, 767–788.

A generalized theory of free torsional vibration for a wide class of suspension bridges with double lateral systems is developed, taking into account warping of the bridge deck cross section and the effect of torsional rigidity of the towers. The analysis is based on a linearized theory and on the use of the digital computer. A finite element approach is used to determine vibrational properties in torsion. Simplifying assumptions are made, and Hamilton's principle is used to derive the matrix equations of motion. The method is illustrated by numerical examples. The objective of the study is to clarify the torsional behavior of suspension bridges and to develop a method for determining a sufficient number of natural frequencies and mode shapes to enable an accurate, practical analysis.

● 6.3-9 Gersch, W. and Martinelli, F., **Estimation of structural system parameters from stationary and nonstationary ambient vibrations: an exploratory-confirmatory analysis,** *Journal of Sound and Vibration,* **65,** *3,* Aug. 8, 1979, 303–318.

The natural frequency and damping parameters of a structure are estimated from a long ambient vibration record that shows considerable nonstationarity. The long record is segmented into 57 approximately independent, one-minute-duration stationary time series segments. Each segment is low-pass filtered to reject unwanted higher frequency modes and is analyzed by a 2SLS (two-stage least-squares) time-domain parametric model procedure. The scatter diagrams of the estimates of the natural frequency and damping parameters exhibit considerable variability. Estimates of the natural frequency and damping parameters and the coefficient of variation expressions of

● *See **Preface,** page v, for availability of publications marked with dot.*

their reliability are obtained by an exploratory-confirmatory data analysis of the 57 vibration time series. A procedure that can obtain the structural parameter estimates with the reliability that is available from stationary analysis from a long and not necessarily stationary record is presented.

● **6.3-10** Davies, H. G. and Rogers, R. J., **The vibration of structures elastically constrained at discrete points**, *Journal of Sound and Vibration*, **63**, *3*, Apr. 8, 1979, 437–447.

The forced vibration of a structure with an added spring constraint acting at a point is discussed. A set of constrained vibration modes is obtained in terms of the assumed known modes of the unconstrained structure, and it is shown that these constrained modes are orthogonal. It is shown in an appendix that the unconstrained modes form a complete set for the constrained beam. The forced vibration response can be described in terms of either set of modes. The two descriptions are shown to be equivalent only if the damping is independent of the mode number. The damping may, however, be an arbitrary function of the forcing frequency.

● **6.3-11** Szemplinska-Stupnicka, W., **The modified single mode method in the investigations of the resonant vibrations of non-linear systems**, *Journal of Sound and Vibration*, **63**, *4*, Apr. 22, 1979, 475–489.

To study the effects of nonlinearities on the resonant vibrations of multidegree-of-freedom systems (lumped parameter or continuous systems), the modified "single nonlinear mode" method is presented. The results obtained are compared to those produced by the commonly used classical single mode method. As an example, a three degree-of-freedom system is examined; the resonance curves are determined by the modified method and by the classical single mode method, and the results are checked using an analog computer. New effects of the restoring force nonlinearity are found; these effects are suppressed by the approximations of the classical single mode method.

● **6.3-12** Mahalingam, S., **On the vibratory response of close-coupled systems**, *Journal of Sound and Vibration*, **63**, *2*, Mar. 22, 1979, 189–200.

Classical theory for the vibratory response of undamped systems to harmonic excitation is extended by the formulation of cross-receptances of close-coupled systems in continued product form. Receptances for force excitation—and, also, transfer ratios for displacement excitation—are represented by formulas of the Biot-Duncan type for straight line and branched torsional systems. Degenerate forms of the receptance diagrams and special modes of response involving partial vibration are discussed in detail.

● **6.3-13** Kircher, C. A. et al., **Seismic analysis of oil refinery structures**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 127–136.

This paper presents the results of experimental and analytical studies of the dynamic characteristics of oil refinery structures (i.e., tall columns). The objectives of the project were to obtain improved knowledge of the dynamic properties of tall columns through combined field measurements and analytical models, to reconcile these results, and to use these results in the evaluation of the seismic design criteria for oil refinery structures.

● **6.3-14** Kostem, C. N. and Heckman, D. T., **Earthquake response of three dimensional steel frames stiffened by open tubular concrete shear walls**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 969–977.

The research program on which this paper is based included the quantitative analysis of the following areas: (1) determination of the vibrational characteristics, and the wind- and earthquake-induced response of a structural system with a symmetric shear core; (2) extension of these studies to a structural system with a shear core damaged during an earthquake; (3) determination of the vibrational characteristics, and the wind- and earthquake-induced response of a structural system with an unsymmetric shear core; (4) effects of considering a live load as an integral part of the mass of a structural system. The earthquake response of a structural system is directly related to the ground excitation and to the stiffness and mass distribution of the structure. One of the indirect but practical measures in the determination of the vibrational characteristics, and consequently the earthquake response, of a structure is the study of the fundamental frequencies of vibration and the corresponding mode shapes. Because extensive tabulations could not be included in this paper, only the variations in the fundamental frequencies of vibration of the structural system are presented. The general observation regarding the behavior of the structural systems in question reveals that, if a three-dimensional dynamic analysis is envisioned because of possible uncertainties, the analysis should be conducted without any simplifications. The simplification to two-dimensional systems may lead to erroneous results, regardless of the sophistication of the method of analysis. Small changes in the dimensions of the shear core do not substantially change the vibrational characteristics of the structural systems. Corresponding design alterations of similar magnitude would not necessitate a new detailed seismic analysis. The contribution of the building's floor system to the building's vibrational characteristics is not negligible. Any accurate analysis must include the floor mass and stiffness. Conversely, the floor system must be designed for maximum dynamic excitations; simplified static analysis and design of floor systems would lead to unacceptable, nonconservative dimensions.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 6.3-15 Leung, Y. T., **Accelerated convergence of dynamic flexibility in series form,** *Engineering Structures,* **1,** *4,* July 1979, 203–206.

In the natural vibration analysis of a structural system, the conventional dynamic flexibility (receptance) matrix in series forms is reexamined. The convergence may be accelerated to a large extent by using the condensed stiffness and mass matrices of the system. Examples involving beams and plates are given. Because only physical coordinates are involved and the size of the system matrices are independent of the number of normal modes taken, the method is suitable for dynamic substructure analysis.

● 6.3-16 Rutenberg, A., **Earthquake analysis of belted high-rise building structures,** *Engineering Structures,* **1,** *4,* July 1979, 191–196.

A modal analysis procedure is presented for the seismic response of belted highrise building structures within the framework of the response spectrum technique. The first three modes of vibration are considered. Natural periods, internal forces, and deflections are computed, and design charts are presented for the parameters of interest. Based on the tentative seismic provisions of the Applied Technology Council (ATC), a numerical example illustrates the use of the charts, and a comparison is made with the ATC equivalent lateral force procedure. The contribution of higher modes of vibration is shown to be very sensitive to small changes in the belt-truss location. It is also shown that the ATC parabolic force distribution is likely to overestimate the top deflection and the moment-related response values.

● 6.3-17 Lu, Z.-A., **Dynamic analysis of cable-hung Ruck-A-Chucky Bridge,** *Journal of the Structural Division, ASCE,* **105,** *ST10,* Proc. Paper 14918, Oct. 1979, 2009–2018.

The hanging-arc structure of the Ruck-A-Chucky Bridge is idealized for finite element analysis as a space assemblage of line elements with beam elements representing the girder and inclined axial elements representing the cables. Correctness of the analysis is verified by a shaking table model. Test and analytical data of the model are compared. Seismic and aerodynamic responses of the two final designs of the bridge (a steel and a concrete) are presented.

6.3-18 Hibbert, J. H., **Synthesis of linear lumped-parameter systems in which a mode shape is partially prescribed,** *International Journal of Mechanical Sciences,* **21,** *12,* 1979, 755–761.

This paper presents a means of synthesizing the inertial elements of a linear lumped-parameter system so that the system will freely vibrate at a prescribed frequency with a mode shape which, although not completely defined, satisfies certain specified requirements. Although the problem cannot normally be solved to give a unique result, it is shown that the solution may be expressed in terms of a linear combination of vectors and associated scalar multipliers, which may assume arbitrary values providing that these lead to non-negative inertial elements. The procedure is illustrated by two numerical examples, the second of which demonstrates a means of extracting mode shape admissibility criteria for systems in which the stiffness matrix is known.

● 6.3-19 Wittrick, W. H. and Horsington, R. W., **On the coupled torsional and sway vibrations of a class of shear buildings,** *Earthquake Engineering & Structural Dynamics,* 7, *5,* Sept.–Oct. 1979, 477–490.

This paper is concerned with the free vibrations of a restricted class of multistory shear buildings in which inertial coupling exists between the torsional and the two sway vibrations. The restrictions imposed are that (1) the shear centers of all stories lie on a vertical straight line, (2) the principal axes of shear are in the same direction in all stories, (3) the centers of mass of all floors lie on another vertical straight line, (4) the radius of gyration about the shear center of every floor mass is the same and (5) the ratios of the two shear stiffnesses to the torsional stiffness do not vary from story to story. The last restriction makes it possible to prove that the $3n$ natural frequencies, normal modes, and generalized masses, where n is the number of stories, can be simply expressed in terms of the products of the three natural frequencies, normal modes, and generalized masses of the single-story, three-dimensional building formed by removing everything above the first floor, with the n natural frequencies, normal modes, and generalized masses of a certain n-story, two-dimensional shear frame. In the special case of a uniform building, a simple closed-form solution, valid for any number of stories, is given.

● 6.3-20 Hawkins, N. M. and Mitchell, D., **Progressive collapse of flat plate structures,** *Journal of the American Concrete Institute,* **76,** *7,* Title No. 76-34, July 1979, 775–808.

Factors influencing the initiation and propagation of progressive collapse in flat plate structures are examined. The mechanism most likely to trigger such collapses is a punching failure at an interior column. The factors dictating punching strength are examined with particular reference to the influences of rotational demands, edge restraints, age at loading, and one-way as opposed to two-way bending. Progressive collapses propagate because of an inadequate moment transfer capacity at surrounding columns. The factors affecting that capacity are examined and the desirability of continuous bottom reinforcement through the column is demonstrated. The merits of four

● *See **Preface,** page v, for availability of publications marked with dot.*

possible defenses against progressive collapse are evaluated: higher live loadings, integral beam stirrup reinforcement, continuous bottom reinforcement, and the provision of a tensile membrane. Recommendations are made for calculations of the strength provided by a tensile membrane and procedures for detailing that membrane.

● **6.3-21** Gardiner, R. A. and Hatcher, D. S., **Material and dimensional properties of an eleven-story reinforced concrete building,** *Structural Div. Research Report 52*, Dept. of Civil Engineering, Washington Univ., St. Louis, Missouri, Aug. 1978, 98.

This paper compares the in-situ structural properties and dimensions, and the specified properties and dimensions of an eleven-story reinforced concrete building. In addition, the effect of the structural variations on the flexural strength of the members is investigated. The conclusions of this paper are that variations of dimensions and properties of the structure are generally similar to those of other buildings, and that the average strength of the members exceeds the design strength.

● **6.3-22** Yamada, M. and Kawamura, H., **Aseismic capacity of steel structures (V)—aseismic characteristics of low-rise steel structures with braces and aseismic effects of bracing elements based on resonance-fatigue-characteristics** (in Japanese), *Transactions of the Architectural Institute of Japan, 284,* Oct. 1979, 69–77.

Earlier papers by the authors proposed a method for evaluating the seismic-resistant capacity of steel structures with symmetric and asymmetric braces. In this paper, the seismic-resistant characteristics of such structures and the effects of bracing elements are investigated on the basis of their resonance-fatigue characteristics. The seismic-resistant characteristics of bracing elements and of structures with symmetric braces in plan are shown in the λ-η plane and the r-b plane, respectively. The resonance response behaviors of structures with asymmetric braces are calculated and presented as case studies.

● **6.3-23** Powell, G. H. and Row, D. G., **Effect of energy absorbing supports on seismic pipe stresses,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 10/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A research program to explore the effects of energy-absorbing restrainers is being conducted at the Earthquake Engineering Research Center at the Univ. of California, Berkeley, under sponsorship of the U.S. Dept. of Energy. Within the program, research is being carried out in several areas. In this paper, preliminary results of the research in one of these areas are presented.

The study is being carried out in several phases. In Phase I, very simple systems were analyzed, to investigate the influence of such parameters as pipe configuration, pipe size, ground motion, restrainer strength, and restrainer location. In Phase II, a somewhat more complex piping configuration was analyzed, and the influence of the same parameters was studied. Only the Phase II analyses are described in this paper. In later phases, progressively more complex systems will be studied, and greater emphasis will be placed on design concepts.

Analyses were first carried out assuming that the restrainers were elastic and essentially rigid. The peak restrainer loads were thus found, and the restrainer strengths for subsequent inelastic analyses were based on these peak loads. Analyses with restrainer strengths equal to (a) 0.7 and (b) 0.3 of the peak load were carried out for each configuration, assuming elastic-perfectly plastic restrainer behavior. Three-dimensional earthquake excitations were applied, using design records for actual power plants. Although the analyses to date have considered only small systems, a number of trends have emerged. For piping systems with moderate amounts of restraint, the analyses show a consistent trend of reduction in pipe stress as the restrainers are allowed to yield. For piping systems which are heavily restrained, the analyses show a consistent trend of increases in pipe stress as the restrainers are allowed to yield. However, the stresses with elastic restrainers are small for such systems, and the stresses remain small as the restrainers yield. There is an overall trend for stresses to be lower with energy-absorbing restrainers than with elastic restrainers. With elastic restrainers, the restrainer loads vary substantially with restrainer location and orientation; and there is no correlation between the load on a restrainer when it is assumed to be elastic and the deformation of the same restrainer when it is allowed to yield. The maximum deformations of yielding restrainers do not appear to be excessive. The number of inelastic cyclic excursions to which a restrainer is subjected increases as the restrainer is made weaker.

● **6.3-24** Gambhir, M. L. and Batchelor, B. de V., **Linear & nonlinear dynamics of cable supported systems,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-1-6.

The paper briefly describes a finite element for studying the free vibration characteristics of a geometrically nonlinear cable-supported system. The element, which allows elastic deformations, is used to determine the frequencies and modes of vibration of single-sagged cable, cable truss, and 3-D cable networks. A parametric study is made to predict the general order of magnitude and the effect of various parameters on the natural frequencies of the cable-supported system.

● **6.3-25** Chandrasekaran, A. R. and Singhal, N. C., **Vibration analysis of circular cylindrical cantilevered structures using axisymmetric finite elements,** *International Conference on Computer Applications in Civil Engineering, October 23–25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-31–36.

Axisymmetric structures have a great variety of applications such as reactor buildings, pressure vessels, domes, fluid containers, cooling towers, chimneys, etc. This paper deals with the dynamic characteristics of uniform, circular, cylindrical, cantilevered structures. The three-dimensional axisymmetric continuum is represented either as an axisymmetric shell or as a solid of revolution. Various types of axisymmetric finite elements, namely, parabolic, paralinear, cubilinear, an element with relative displacement degrees-of-freedom, and an element proposed by Ahmad have been studied and compared. A parametric study involving the height and the thickness of the shell as variables has been carried out. It is concluded that the element with relative displacement degrees-of-freedom can be used over the entire range whereas other elements can be used only for restricted cases.

● **6.3-26** Ross, C. T. F., **Vibration of a model tower,** *International Conference on Computer Applications in Civil Engineering, October 23–25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-51–54.

A model tower, constructed from brass tubes, was vibrated by an electromagnetic shaker and modes of vibration and the corresponding frequencies were observed. An investigation was also carried out to determine the effect on vibration of adding a mass to the top of the tower. A theoretical investigation was also conducted on the effect on vibration of applying a downward compressive axial force to the top of the tower. The theoretical investigations were made using the finite element method, and these showed good agreement with the experimental observations.

● **6.3-27** Liu, T. H., Loceff, F. and Anderson, P. H., **Seismic analysis of Category I crane structures,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/9, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

Presently, most safety class crane seismic analyses are done by use of the equivalent static method or the response spectra analysis method. In these methods, the crane is considered linear and elastic. These assumptions are considered adequate when the crane is at its "parked position" with many additional tiedowns. However, at the "operating position" of the crane, the crane has to remain on the crane rails and the hoist has to maintain its load in the event of an earthquake. This paper presents the analytical study of the impact effects resulting from seismic loadings on a crane structure considering structural nonlinearities. Such nonlinearity comes mainly from the hoist cable that can only resist tension and from the gap in the support with the seismic hold-down mechanism.

In the parked position, the hoist cable experiences tension during normal crane operation. Because of the cyclic nature of the seismic loading, the weight at the end of the cable may move upward fast enough to overcome the tension in the cable. In the operating position, the wheels of the crane normally rest on the rail. In order to prevent the uplifting of the wheels, seismic hold-down bars with gaps are constructed. These gaps are required for clearance and thermal expansion. It is recognized that rocking caused by seismic loading can open or close the gaps. Support reactions from the geometric nonlinearities will be different than the support reaction using the assumption of linear supports. To obtain effects caused by the nonlinearities, a time history analysis is employed for the finite element model. It is impractical to perform such time history analysis on every seismic Category I crane structure.

In the present study, a containment polar gantry crane is analyzed by time history and response spectra methods. To provide for a comparison of the results, a synthetic time history generated from corresponding response spectra is used for the time history analysis. Results from these two analyses are compared and nonlinear time history dynamic load factors are determined for critical seismic forces of hoist load and support loads. Such load factors are very useful for the crane designer and the stress analyst in their design and analysis of the crane as a seismic Category I structure.

● **6.3-28** Canetta, G., **Membrane versus shell type elements in F.E. analysis of box type buildings,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 3/4, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

A finite element analysis is discussed for box-type buildings under gravity, seismic, and temperature loads. The computational effort differs depending upon whether membrane- or shell-type elements are used. The relevance of membrane and bending stress components to the total stress distribution is outlined in tabular form, and the different role of the typical members under the various loading conditions is emphasized. The adequacy of a finite element model based on shell-type elements for the foundation mat and membrane-type elements for the walls and floor slabs is discussed. It is found by means of sample models and case histories that the overall displacements of the structure relative to the foundation slab differ no more than a few percent in the general case from the respective values computed on the basis of a more sophisticated model when bending stiffness is taken into account.

● **6.3-29** Heins, C. P. and Sahin, M. A., **Natural frequency of curved box girder bridges,** *Journal of the Structural Division, ASCE,* **105,** *ST12,* Proc. Paper 15064, Dec. 1979, 2591-2600.

This paper presents the results of a comprehensive study which has permitted the development of a series of empirical equations used for direct evaluation of the natural frequency of straight and curved box girders. The natural frequency of curved box girders has been obtained by utilizing a computer-oriented finite difference scheme. The natural frequency results obtained from the computer program were compared to the measured frequencies of a series of test bridges. Excellent correlation was observed. A parametric study was then performed on a series of simple-two-, and three-span continuous curved bridges. The results from this parametric study permitted development of a simplified natural frequency equation.

● **6.3-30** Lehmkamper, O., **Reinforced concrete cooling tower shells** (Versteifte Kuhlturmschalen aus Stahlbeton, in German), *Mitteilung 78-6,* Inst. fur Konstruktiven Ingenieurbau, Ruhr-Univ. Bochum, West Germany, July 1978, 136.

A kinetic method is presented to determine the linear buckling and vibration properties of unstiffened and stiffened hyperboloidal cooling tower shells made of reinforced concrete and a parametric study is carried out using finite elements. The following parameters are varied: the type of axisymmetric load, the main geometric dimensions, the curvature of the meridional function, and the type of stiffening, that is, the number, dimension, and arrangement of meridional ribs and stiffening rings. The numerical results are interpreted and recommendations are given.

● **6.3-31** Kratzig, W. B. and Meskouris, K., **Simplified earthquake analysis of natural draught cooling towers** (Vereinfachte Erdbebenberechnung von Naturzugkuhlturmen, in German), *Mitteilung 78-5,* Inst. fur Konstruktiven Ingenieurbau, Ruhr-Univ. Bochum, West Germany, Aug. 1978, 96.

Past methods for the analysis of the seismic response of natural draft cooling towers, including their supports and foundations, have been based on shell finite elements. These methods require extensive computer systems and a great deal of computer time. The method presented in this report adopts a different approach. By assuming a rigid-base seismic translational excitation, the response of cooling towers can be approximated by beam-like shapes of deformation. As a first approximation, this allows the application of beam elements which take shear distortion and rotary inertia into account. An improved, slightly more complicated model is based on the membrane theory of conical shells. The transfer matrix method is used to determine mode shapes and natural frequencies. Dynamic stress results and deformations of the cooling tower are calculated based on the response spectrum method. The computer program developed leads to results that agree very well with those achieved by more extensive systems while requiring much less computer time.

● **6.3-32** Lubliner, J., **Studies on high-frequency vibrations of buildings - 1: the column effect,** *UCB/EERC-79/21,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 30. (NTIS Accession No. PB 80 158 553)

It is shown that, when column mass is taken into account in the vibration of buildings, the system acquires additional degrees-of-freedom. If column mass is small compared to floor mass, then the modes obtained from conventional analysis persist virtually unchanged; the additional modes involve almost exclusively column motion, the characteristic frequencies being in the low audio range. The nature of the modes, as well as the transmission of ground motion, depend upon whether the columns in adjacent stories are tuned to each other.

● **6.3-33** Rosman, R., **Vibrations of spatial building structures,** *Environmental Forces on Engineering Structures,* 415-423. (For a full bibliographic citation, see Abstract No. 1.2-28.)

On the basis of an extremum principle, a simple hand-calculation method is developed for the determination of the fundamental vibration period and the corresponding rotation axis of a frequent type of contemporary building structure, the mass axis of which does not coincide with its stiffness axis. It is shown that, as a result of the coupling of the flexural and torsional vibrations, the structure's vibration period might be appreciably larger than its largest uncoupled vibration period. Moreover, the plane of the lateral load is determined, which produces a deformation corresponding to the fundamental mode vibration. The structure is the weakest when loaded in this plane. A corresponding wind load produces the largest dynamic effect and might, hence, be a governing factor when designing the building's structure. An example illustrates the practical application of the method.

6.3-34 Hamada, M., **Earthquake observation and numerical analysis of underground tank,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 319-322. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 273,* May 1978, 1-14.)

● See ***Preface,*** *page v, for availability of publications marked with dot.*

A numerical method is proposed for analyzing the deformation and the stresses of underground tanks during earthquakes, based on the results of the earthquake observations of a tank in a soft alluvial ground. The dynamic characteristics of the stresses of the tanks are studied and nomograms for earthquake-resistant design are given.

6.4 Deterministic Dynamic Behavior of Linear Structures

● 6.4-1 Tomii, M. and Hiraishi, H., **Elastic analysis of framed shear walls by considering shearing deformation of the beams and columns of their boundary frames (Part III: numerical examples)**, *Transactions of the Architectural Institute of Japan*, *275*, Jan. 1979, 45-53.

In this paper, a numerical example of the elastic analysis of a single-span shear wall is presented. Also shown are equations for the elastic analysis of continuous shear walls and an example calculated by means of the equations.

● 6.4-2 Tomii, M., Sueoka, T. and Hiraishi, H., **Elastic analysis of framed shear walls by assuming their infilled panel walls to be 45-degree orthotropic plates (Part I: analysis of single-span shear walls)**, *Transactions of the Architectural Institute of Japan*, *280*, June 1979, 101-109.

Airy's stress functions are used to derive equations for the elastic analysis of single-span shear walls with infilled panels assumed to be 45-degree orthotropic elastic plates. Numerical examples are presented.

● 6.4-3 Picard, A., **Lateral load resisting systems in steel structures** (Systemes de resistance aux forces laterales dans les charpentes d'acier, in French), *Third Canadian Conference on Earthquake Engineering*, Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 779-809.

This paper is a state-of-the-art report concerning lateral load resisting systems in steel structures. The behavior of these systems is described, and innovations tried in the past are discussed. The distribution of the horizontal forces to the various elements of the lateral load resisting system is also discussed.

● 6.4-4 Popplewell, N. and Youssef, N. A. N., **A comparison of maximax response estimates**, *Journal of Sound and Vibration*, **62**, *3*, Feb. 8, 1979, 339-352.

Formulas for estimating the maximax response of linear stable structures to incompletely described loads are reviewed. The accuracies of these formulas are evaluated for fairly comprehensive, but ideal, circumstances where the loads and, hence, the exact solutions are known fully. One of the formulas is less accurate, but the ranking of the others appears to depend upon the load information and damping.

● 6.4-5 Kawashima, K. and Penzien, J., **Theoretical and experimental dynamic behaviour of a curved model bridge structure**, *Earthquake Engineering & Structural Dynamics*, 7, 2, Mar.-Apr. 1979, 129-145.

This paper presents correlations between the analytical and experimental seismic responses of a curved model bridge structure which was constructed to have the same features as a typical full-scale high curved highway bridge structure. The dynamic behavior and seismic response of the experimental bridge model are examined with particular emphasis on the discontinuous behavior of expansion joints. Modeling of Coulomb-type friction with slippages and impacting at the expansion joints is described. Correlations of displacement response of the bridge model carried out for three seismic excitations are presented. Parameter studies conducted to assist in the interpretation of correlation results are presented and the characteristics of the dynamic behavior of the bridge model are discussed.

● 6.4-6 Lee, T. H., **Axisymmetric seismic response of a thick circular plate supporting many rods by modal synthesis**, *Earthquake Engineering & Structural Dynamics*, **7**, *3*, May-June 1979, 235-251.

The dynamic response of a thick, horizontal, circular plate supporting a large number of slender rods subjected to uniform boundary motion in the vertical direction has been studied by synthesizing component modes of continuous substructures. The excitation considered corresponds to the vertical component of boundary movement produced by earthquake disturbances and the axisymmetric response problem was solved. The Mindlin theory was used to formulate the component equations of the plate which is treated as the main component in a modal synthesis technique. The slender rods, which are attached vertically to the plate, are handled as branch components. Vibration modes of a classical thin plate were used as the initial displacement functions for the Mindlin plate. These functions subsequently were modified by a component mode improvement process to obtain plate modes. System modes were generated by combining the improved plate modes with component modes of rods. Numerical results for the natural frequencies and the time-history response of the coupled system are compared with the results given by a three-dimensional finite element method.

● 6.4-7 Irie, T., Yamada, G. and Takahashi, I., **Determination of the steady state response of a Timoshenko beam of varying cross-section by use of the spline interpolation technique**, *Journal of Sound and Vibration*, **63**, *2*, Mar. 22, 1979, 287-295.

● *See **Preface**, page v, for availability of publications marked with dot.*

The steady-state response of an internally damped Timoshenko beam of varying cross section to a sinusoidally varying point force is determined by use of the spline interpolation technique. With the beam divided into small elements, the response of each element is expressed by a quintic spline function with unknown coefficients. The response is obtained by determining these coefficients so that the spline function satisfies the equation of motion of the beam at each dividing point and also satisfies the boundary conditions at both ends. In this case, the slope resulting from pure bending of the beam is conveniently adopted as the function essentially expressing the response, from which the transverse deflection, driving point impedance, transfer impedance, and force transmissibility of the beam are derived. The method is applied to cantilever beams with linearly, parabolically, and exponentially varying rectangular cross sections; these responses of the beams are calculated numerically, and the effects of the varying cross section on the responses are studied.

● **6.4-8** Wilson, J. C. and Heidebrecht, A. C., **Seismic response of equipment in multi-story structures: response evaluation and test simulation,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 543-552.

This paper concentrates on two aspects of the problem of earthquake-sensitive equipment in multistory structures: (1) examination of the characteristics of the seismic environment at equipment mounting locations in the buildings, and (2) utilization of shaking table tests as a means of examining the seismic adequacy of equipment test specimens. The development of meaningful seismic qualification testing programs based on dynamic response characteristics typical of many buildings is of practical concern to utilities and public service facilities in seismic areas.

● **6.4-9** Zimmerman, R. M. and Brittain, R. D., **Seismic response of multi-simple span highway bridges,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1091-1120.

Multiple single-span bridges have become very popular on freeways and turnpikes. The independence of the spans has many design advantages, but such spans can have a higher seismic risk because of the lack of continuity in the longitudinal direction. This study focuses on modeling techniques using the program features of ICES-STRUDL-II. Seismic loads were simulated using undamped sinusoidal forcing functions and were checked using an El Centro earthquake simulation. A three-span bridge structure is modeled as a fixed support and a roller support, and the techniques and results are compared. The latter support was developed so that traveling wave effects could be determined on long bridges. A welded rocker-type connection is modeled as a multi-stage linear structure. Computed quantities include resonant frequencies, mode shapes, and motions of various structural components. The results indicate that bridges that have high rocker-type supports have relatively low natural periods and can be shown to be susceptible to failure resulting from impacting between adjacent spans or excessive relative motion between span ends and pier caps.

● **6.4-10** Kristek, V., **Folded plate approach to analysis of shear wall systems and frame structures,** *Proceedings, The Institution of Civil Engineers,* Part 2, **67**, Paper No. 8289, Dec. 1979, 1065-1075.

A simple, approximate method of analysis of shear wall systems is presented. A substitute structure is formed so that boundary conditions allowing the use of folded plate theory are fulfilled. The substitute structure is divided into folded plate elements; for shear walls with openings and framework panels, special elements are introduced. Stiffness matrices for such elements are derived. The structure matrix is formed by assembly of the stiffness matrices of the elements. Floor slabs are regarded as diaphragms of the folded plate system. The analysis can be carried out by introducing minor adjustments into existing folded plate computer programs.

● **6.4-11** Ahmadi, G., **On the application of the critical excitation method to aseismic design,** *Journal of Structural Mechanics,* 7, *1,* 1979, 55-63.

The critical excitation of linear structures subjected to earthquake support motion is investigated. For a given time duration and peak ground acceleration, the critical time history which maximizes the absolute acceleration response is obtained. Similar considerations are given to the critical ground acceleration which maximizes the relative displacement and velocity responses. Some bounds on the response spectra curves are obtained and discussed.

6.4-12 Hirst, M. J. S., **Application of the finite-stringer theory to the interaction of walls and their supporting structures,** *International Journal of Mechanical Sciences,* **21**, *10,* 1979, 631-635.

This paper presents further developments in a previously published method for the elastic analysis of walls acting compositely with their supporting structure. The method can be readily programmed for a small computer. The simplicity of the method permits the production of design graphs using a rational scheme given in the paper.

● **6.4-13** Yamada, Y. and Okumura, H., **Dynamic finite element analysis of multilayer sandwich beams** (in Japanese), *Seisan-Kenkyu,* **31**, *3,* Mar. 1979, 64-67.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● **6.4-14** Tomii, M. and Hiraishi, H., **Elastic analysis of framed shear walls by assuming their infilled panel walls to be 45-degree orthotropic plates (Part II: numerical examples),** *Transactions of the Architectural Institute of Japan, 284,* Oct. 1979, 51-60.

In Part I of this study (see Abstract No. 6.4-2), the elastic analysis of single-span shear walls assumed to be 45-degree orthotropic elastic plates was reported. In this paper, numerical examples of shear walls A and B subjected to the external forces caused by earthquakes are given. The paper also discusses the ways in which the stress distribution and deformation of the boundary frame and wall change as the diagonal shear cracks of the wall propagate and the diagonal tension of the concrete becomes unreliable.

● **6.4-15** Howard, G. E. and Ibanez, P., **Analytical and experimental investigation of the dynamic response of underground nuclear power plants,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 7/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper summarizes a preliminary assessment of the earthquake engineering implications of siting nuclear power facilities underground. The study is illustrative in its considerations and comparisions of nuclear power facilities sited on the surface and underground. The results are believed to be adequate for the satisfaction of the objectives of the study, i.e., the establishment of bounding characteristics for the underground seismic design problem. The major findings of the study were (1) Placement of structures below grade can result in reductions in internal equipment dynamic loads of a factor of two or more as compared to surface facilities. (2) Observations of earthquake-induced motion as a function of depth for small amplitude events suggest a strong reduction with depth. For large amplitude events, this reduction may not be as great. (3) To the extent that current analysis procedures are acceptable for surface sited plants, such procedures should be generally applicable to subsurface facilities. The treatment of soil-structure interaction during large earthquakes represents the possible major exception to this observation, and probably requires the use of nonlinear soil models. However, this is true for both surface and buried plants. It is felt, however, that, for the purpose of obtaining a preliminary comparison between surface and buried plants, linear methods should suffice.

Subsequent to the above analytical investigations, an experimental comparative response investigation was conducted for a partially embedded (5 percent of height) and fully buried (one height soil overburden) cylindrical concrete structure subjected to explosive-generated ground waves. Structures were approximately 1/25-scale models of PWR containment structures, with height and diameter of 2.3 m and 1.5 m, respectively. These tests, supported by the Electric Power Research Inst., were executed with planer arrays of buried explosives. Comparing response spectra from resulting time histories tended to confirm the analytical trends; reductions of a factor of about two were noted with burial.

● **6.4-16** Tansirikongkol, V. and Pecknold, D. A., **Equivalent linear SDF response to earthquakes,** *Journal of the Structural Division, ASCE,* **105**, *ST12,* Proc. Paper 15073, Dec. 1979, 2529-2545.

The objective of this paper is to examine the accuracy of an equivalent linearization method for prediction of the maximum response of a single degree-of-freedom bilinear hysteretic oscillator subjected to an earthquake input. Simple expressions are developed for equivalent linear frequency and damping in terms of maximum attained response ductility. Comprehensive numerical results are presented in which the effects on accuracy of the elastic frequency, yield strength, bilinear hardening slope, initial viscous damping, and earthquake input are examined. The parameters that most strongly influence accuracy are the hardening slope of the bilinear hysteresis loop and the magnitude of the response ductility. Accuracy is poorest for nearly elastoplastic systems and moderate response ductilities. These trends are interpreted by examining the response of the bilinear oscillator to simple inputs in the frequency domain.

● **6.4-17** Strenkowski, J. and Pilkey, W., **Transient response of continuous viscoelastic structural members,** *Journal of Applied Mechanics, ASME,* **46**, 3, Sept. 1979, 685-690.

In this paper, a comprehensive theory with a constitutive relationship in the form of a hereditary integral is formulated for the dynamic response of structural members. A modal approach is used to uncouple the response caused by an arbitrary excitation force and by general nonhomogeneous surface tractions. The result of this theory is a general set of formulas which may be used for both nonself-adjoint and self-adjoint systems of governing equations of motion. This general formulation is applied to the specific cases of a Voigt-Kelvin beam and a viscoelastic circular plate.

● **6.4-18** Mengi, Y. and McNiven, H. D., **A mathematical model of masonry for predicting its linear seismic response characteristics,** *UCB/EERC-79/04,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 115. (NTIS Accession No. PB 298 266)

This report represents work that is part of a study of the seismic behavior of masonry. The major part of the work is experimental, but this part is devoted to developing a mathematical model for masonry which could be used to

● *See* ***Preface****, page v, for availability of publications marked with dot.*

derive the elastic stress field in a wall or pier subjected to seismic loads. Because masonry is made of two materials, and because its geometry is so complicated, it is necessary in studying stress fields that could arise to replace the composite material by a homogeneous one. The model material must display the same constitutive characteristics as the prototype and must have the same wave dispersive properties. It is the mathematical model of such a homogeneous material that is developed in this report.

The development is made in three steps. In the first, a general theory is constructed for two-phase materials. The method employed uses the theory of mixtures applied to a two-phase material in which the phases reflect a periodic structure and in which each phase is linearly elastic. Employing the fundamental equations of the theory of mixtures, the governing equations of a linear approximate theory are established. The theory, valid for an arbitrary direction of motion, replaces the composite by a homogeneous, two-phase, anisotropic, elastic solid. It accommodates the dispersive nature of the composite by means of an elastodynamic operator, which is introduced into the constitutive relations of the linear momentum interactions.

The second step is to adapt the general theory to a particular geometry. The periodic material chosen is made of alternate plane layers. This geometry is chosen for two reasons: first, the geometry of masonry can be accommodated within it, and second, the wealth of analytical and experimental material concerning the dynamic behavior of such materials. The choice of geometry affects both the constitutive equations and the elastodynamic operators.

The theory for layered materials contains nineteen model constants and equations are developed from which these constants can be derived from the layered constants. The equations are derived partly using micromodel analysis and partly by matching specific dynamic behaviors of the model and prototype. The ability with which the model predicts the dynamic response of the layered material is assessed in two ways. Both ways compare spectra reflecting the behavior of infinite trains of the principal kinds of waves. The first compares spectral lines from the model with those derived from the exact theory for layered materials. The second compares lines from the model with those obtained from experiments. Predictions from the model prove to be quite accurate.

In the third phase, the model is appraised by comparing the responses predicted by the model for a transient input with those observed experimentally. Experimental data permit comparisons of the behavior of dilatational waves travelling both parallel and perpendicular to the layers in plates and semi-infinite bodies. Where possible, comparison is also made with responses predicted by the exact theory. Responses in the model are found using the method of characteristics. Comparison, which is exhibited in a number of figures, shows that the responses predicted by the theory are quite accurate. The accuracy is not restricted to early arrival times but extends to behavior far behind the head of the pulse.

6.4-19 Matselinskii, R. N. and Spannut, L. S., **KZhS type panel-shells for seismically active areas** (Paneli-obolochki KZhS dlya seismicheskikh raionov, in Russian), *Beton i zhelezobeton, 10,* Oct. 1979, 25–27.

Recent successful use of panel-shells in highly seismic areas in the U.S.S.R. is discussed. The shells are designed for use in the roofs of single-story industrial, public, and farm buildings. Data are provided for various concretes, the elastic and creep responses of the shells, and the horizontal and vertical components of seismic inertial forces acting on the structures.

6.5 Nondeterministic Dynamic Behavior of Linear Structures

6.5-1 Ahmadi, G. and Satter, M. A., **Response of plate to nonstationary random load,** *The Journal of the Acoustical Society of America,* **65,** *4,* Apr. 1979, 926–930.

The response of a rectangular plate subjected to nonstationary random load is studied. The general expressions for the autocorrelation and the mean square displacement are derived and discussed. A similar study was carried out for the stress components. The random excitation is then assumed to be a modulated white-noise or narrow-band process. It is shown that, when the damping coefficient is small, simple approximate expressions can be obtained for the variances of the lateral displacement as well as the stress components. Several examples using a simply supported plate are presented.

6.5-2 Langley, A. J. and Taylor, P. H., **Chladni patterns in random vibration,** *International Journal of Engineering Science,* **17,** *9,* 1979, 1039–1047.

The presence of Chladni-like patterns of enhanced response on both a taut string and a thin elastic plate under single point random excitation is demonstrated theoretically using a reverberation field method of analysis. The statistics of the wavefield for the plate are established, and the field correlation is shown to be a δ-function. It is shown for the string that the details and width of the zones of enhanced response can be found simply in terms of the autocorrelation function of the excitation.

● **6.5-3** Gasparini, D. A., **Response of MDOF systems to nonstationary random excitation,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM1,* Proc. Paper 14341, Feb. 1979, 13–27.

● See ***Preface,*** *page v, for availability of publications marked with dot.*

Responses of linear dynamic systems to nonstationary random excitation are calculated using a state formulation. Analytical expressions for evolutionary covariance matrices are derived for the case of evolutionary white noise excitation. As an example, responses of a 4-DOF system to ground acceleration are calculated. Modal decomposition is utilized and the relative importance of the cross covariance among the modes is quantified. Approximate first passage probabilities for high thresholds are calculated by using the evolutionary variances of a response and its time derivative and by making the Poisson assumption. An augmented dynamic system is proposed for the case of nonwhite excitation. The transition matrix for the augmented system is given.

● **6.5-4** Tsuchiya, M. and Shibata, H., **Seismic reliability analysis of lifeline systems (2)**, *Seisan-Kenkyu,* 31, *2,* Feb. 1979, 41–44.

In previous reports, the authors discussed a methodology for the seismic risk assessment of lifeline systems using terminal reliability and flow reliability as measures of seismic risk. This report deals with a measure of seismic importance for lifeline systems largely based on a sensitivity analysis of terminal reliability. Some general characteristics of this importance are clarified.

● **6.5-5** Sakata, M. and Kimura, K., **The use of moment equations for calculating the mean square response of a linear system to non-stationary random excitation**, *Journal of Sound and Vibration,* **67**, *3,* Dec. 8, 1979, 383–393.

The moment equations approach is used to calculate the mean square response of a linear system to nonstationary random excitation which is expressed as a product of a deterministic envelope function and a Gaussian stationary non-white noise. The moment equations are derived by performing single integrations in the time domain and are solved numerically by digital computer. Numerical examples are given for the response of single and two degree-of-freedom systems which are excited by noise with an exponentially decaying harmonic correlation function. It is shown that an overshoot, in the sense that the transient response exceeds its stationary value, may occur even in the case of an exponential envelope function, but that the response does not exhibit overshoot when the natural frequency of the system is almost coincident with the dominant frequency of the input.

6.6 Deterministic Dynamic Behavior of Nonlinear Structures

● **6.6-1** Yamada, M. and Kawamura, H., **Aseismic capacity of steel structures (III)-low-rise rigid frames with symmetric braces** (in Japanese), *Transactions of the Architectural Institute of Japan, 278,* Apr. 1979, 55–66.

In Parts I and II, the seismic-resistant capacity of steel structures without braces was discussed. In this paper, the capacity of lowrise steel structures, composed of rigid frames with elastic and/or plastic-buckling-type braces arranged symmetrically in plan, is studied. The mechanical behaviors of a single brace subjected to alternately repeated axial loading are described by means of brief formulas. Steel structures with braces are divided into two types: rigid and flexible. An approach for analyzing the resonance-fatigue characteristics of flexible-type steel structures with braces is shown on the basis of idealized and simplified restoring functions and hysteretic area characteristics of braced and rigid frame elements. Criteria and procedures for evaluating the capacity and safety of rigid steel frames with braces are presented.

● **6.6-2** Naka, T., Morita, K. and Tachibana, M., **Strength and hysteretic characteristics of steel-reinforced concrete columns with base** (in Japanese), *Transactions of the Architectural Institute of Japan, 276,* Feb. 1979, 43–51.

Beam-column tests were conducted of steel-reinforced concrete columns with steel elements pin-connected by anchor bolts at the base. The steel and the reinforced concrete elements composing the columns react as a unit until the flexural crack occurs at the base of the columns, but the elements react separately thereafter. Until the maximum strength of the columns is reached, the inflection points of the steel and the concrete elements approximately coincide. By considering an equation and a model given in the paper, the flexural cracking strength at the base of the columns can be estimated. Estimation of the shear cracking strength at the base of columns can be accomplished by an equation presented in the paper. Based on Navier's assumption, the flexural yield and the maximum strength of the base of the columns can be estimated. Somewhat overestimated by means of the superposed flexural strength is the flexural yield strength; however, the flexural maximum strength can be correctly estimated by means of the superposed flexural strength.

● **6.6-3** Muto, K. and Kobayashi, T., **Nonlinear rocking analysis of nuclear reactor buildings-simultaneous horizontal and vertical earthquake inputs** (in Japanese), *Transactions of the Architectural Institute of Japan, 276,* Feb. 1979, 69–77.

In this paper, the dynamic behavior of a BWR (MARK-I)-type nuclear reactor building is studied. A geometrical nonlinearity based on the uplift of the base mat when subjected to the 1940 El Centro earthquake is applied as input. Responses are compared for the following

● *See **Preface,** page v, for availability of publications marked with dot.*

cases: Case 1—the NS (max. 0.5 g) and vertical (max. 0.3 g) components are applied simultaneously as the horizontal and vertical inputs, respectively; Case 2— only the NS (max. 0.5 g) component is applied as the horizontal input.

● **6.6-4** Okada, T. and Seki, M., **Nonlinear earthquake response of reinforced concrete building frames by computer-actuator on-line system (Part I: objective and methodology)** (in Japanese), *Transactions of the Architectural Institute of Japan, 275,* Jan. 1979, 25–31.

Nonlinear seismic response of reinforced concrete frames to a recorded ground motion was simulated by a newly developed computer-actuator on-line system and compared with a computer simulation accomplished by means of the program OS-1D. This paper, the first part of a five-part report, describes the overall objective of the project and the methodology used in the simulation. The on-line system is an electrohydraulic jack system and the program OS-1D is a simplified fiber model analysis based on the nonlinear stress-strain relationships of concrete and steel reinforcement.

● **6.6-5** Suzuki, T. and Tamamatsu, K.-I., **Experimental study on energy absorption capacity of columns of low steel structures (Part 1: energy absorption capacity of H-shaped steel columns subjected to monotonic loading and cyclic loading with constant deflection amplitudes)** (in Japanese), *Transactions of the Architectural Institute of Japan, 279,* May 1979, 65–75.

This series of experiments investigates the energy-absorption capacity of H-shaped steel columns subjected to earthquake loads. The results are given of tests of columns subjected to monotonic and cyclic loading with constant deflection amplitudes combined with axial loads. Three equations are presented. The first equation represents the approximate relationships between energy-absorption capacity E_{CM} and plastic deflection capacity D_{MAX} subjected to monotonic loadings. For cyclic loading with constant deflection amplitudes in which lateral deformation is developed in the first cycle, the second equation relates the energy-absorption capacity E_C to the plastic deflection amplitude D on a linear log-log scale. Because the point D_{MAX}, E_{CM} on the log-log scale may be located on the line given by the second equation of the same shaped member, a third equation is provided by substitution of the first equation into the second equation.

● **6.6-6** Okada, T. and Seki, M., **Nonlinear earthquake response of reinforced concrete building frames by computer-actuator on-line system (Part II: on-line test series-1)** (in Japanese), *Transactions of the Architectural Institute of Japan, 279,* May 1979, 77–84.

Five frames of the column-yielding type with strong and stiff beams were tested by means of an on-line system. Test variables were the initial natural period of the frame and the intensity of the ground motion. Computer simulation using the program OS-1D showed a good approximation to the on-line simulation.

● **6.6-7** Imai, H. and Kosugi, K., **Studies on elastic and plastic properties of SRC-framed shear walls (Part 1: restraining effects of frames seen from indirectly measured values)** (in Japanese), *Transactions of the Architectural Institute of Japan, 280,* June 1979, 91–100.

This paper examines the results of an analysis of indirectly measured values obtained for six shear walls comprising steel-reinforced concrete frames with different types of reinforcement and reports on the influence that the elastic and plastic properties of the shear walls have on the degree of restraint of peripheral frames.

Prior to cracking of the wall concrete and the peripheral frame, the wall panel is in an approximate pure shearing state, and stresses and strains of the frame and wall are distributed roughly antisymmetrically. When the wall panel cracks, it forms a compression field. Because the peripheral frame as a whole restrains the wall panel, the tensile stresses of the peripheral frame become fairly large. Most of the shear forces after cracking of the wall panel are carried by the wall diagonal members which are restrained by the frame; the wall reinforcement carries shear forces approximately equivalent to the tensile strength of the concrete. The shear force carried by the deformation of the rigid frame is small. The axial stress-strain relationship of a column is represented by a stiffness curve with the entire cross section, including the concrete of the frame, reacting effectively during compressive stress. During tensile stress, the relationship approaches the stiffness curve of only the structural steel and reinforcing bars as repetitive stresses are sustained. The bending stiffness of a column differs according to the condition of axial stress. During tensile stress, it approaches the stiffness of structural steel and reinforcing bars only; but, during compressive stress, the concrete is also fairly effective. The shearing stiffness of a column also differs according to the condition of axial stress. During compressive stress, the column stiffness approximates the stiffness of the entire cross section, but the column stiffness is fairly low during tensile stress. The degree of reduction is not as sharp as that for bending stiffness, and concrete also is fairly effective against shearing stress.

● **6.6-8** Seki, M. and Okada, T., **Nonlinear earthquake response of reinforced concrete building frames by computer-actuator on-line system (Part III: on-line test series 2)** (in Japanese), *Transactions of the Architectural Institute of Japan, 280,* June 1979, 79–89.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

The data for test series 2 are presented. Test variables were the initial natural period, the intensity of the ground motion, and column axial stress. From the two on-line test series, it is found that the computer-actuator on-line system used in the tests is a feasible method for simulating experimentally the earthquake response of reinforced concrete building frames and that the computer program OS-1D provides a good approximation of the on-line simulation.

6.6-9 Spencer, A. J. M., **Impulsive loading of fibre-reinforced rigid-plastic plates,** *International Journal of Engineering Science,* **17,** *1,* 1979, 35-47.

A theory for analyzing the dynamic deformations of ideal fiber-reinforced rigid-plastic plates is applied to the problems of subjecting circular and rectangular plates to uniformly distributed impulsive loads. The resulting permanent deflections are compared with the deflections predicted by means of the theory for unreinforced plates. It is found that ideal reinforcement reduces the maximum deflection by a factor which is of the order of magnitude of the aspect ratio of the plate.

● 6.6-10 Cheng, F. Y., Oster, K. B. and Kitipitayangkul, P., **Establishment of ductility factor based on energy absorption and evaluation of present methods,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 719-744.

This paper reviews two conventional definitions of ductility factor on the basis of rotation and curvature and proposes two new formulations based on the dissipated strain energy. The advantages and disadvantages of each of the methods are discussed and illustrations are provided. These four ductility definitions are employed in the seismic response studies of a ten-story, one-bay plane rigid frame and a ten-story, one-bay three-dimensional building system with concrete floors and steel columns. The plane structure is subjected to two-dimensional ground motions and the responses of the three-dimensional building are a result of the interacting earthquake motions, of which two are horizontal and one is vertical. The numerical examples reveal that the ductility definitions based on energy are more suitable to interacting ground motions than the conventional definitions and that the interacting earthquake motions can demand larger ductilities than those for one-dimensional motion.

● 6.6-11 Kostem, C. N. and Branco, J. A., **Earthquake response of steel frame-cracked concrete shear wall systems,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 969-988.

The results are presented of a parametric investigation of the earthquake response of structural systems composed of steel frames and reinforced concrete shear frames. The investigation included two three-bay steel frames of 10 and 24 stories, respectively. The reinforced concrete shear walls are assumed to be intact, and, during different phases of the investigation, to have various degrees of cracking caused by the previous earthquake. The comparisons in terms of the changes in the natural frequencies of vibration for undamaged and damaged shear walls are tabulated. As an indicator of the response of the structural system, the lateral deflection profiles of the structural system when subjected to various ground motions are included in graphical form. The parametric investigation included the earthquake response of the frames when the structural system is subjected to three different types of ground motion spectra. It is found that the structural response changes substantially, depending upon the type of ground motion employed. It is also noted that the changes in the earthquake response of the structural system are not as extensive as would have been expected for structural systems having different structural deteriorations.

● 6.6-12 Fintel, M. and Ghosh, S. K., **Effect of wall strength on the dynamic inelastic seismic response of yielding wall-elastic frame interactive systems,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 949-968.

In current practice, shear wall-frame interactive systems subjected to earthquakes are considered to dissipate energy primarily through yielding in the frame joints, while the walls are considered to remain elastic. This paper shows that keeping the frames elastic and designing the shear walls for yielding makes it possible to avoid difficult ductility details in the frame, while incorporating ductility details in the walls where required. An analytical investigation using inelastic response history analysis is used to study the earthquake response of yielding wall-elastic frame structures for a limited range of varying structural parameters. This paper describes the results of the study concerning the effect of wall strength on the response of yielding wall-elastic frame systems.

● 6.6-13 Pall, A. S. and Marsh, C., **Seismic response of large-panel structures using limited-slip bolted joints,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 899-916.

Large-panel concrete construction offers many technical and economical advantages over conventional methods, but in seismic regions such structures are viewed with suspicion. This paper investigates the seismic response of panel buildings using energy dissipating, limited-slip, bolted joints. Bolted joints have previously been used for

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

large panel structures, basically as an alternative to structural grouted joints for the purpose of extending the benefits of industrialization to the erection procedure. The paper proposes the use of specified additional clearance in the slotted holes to provide a potential for limited slip in the vertical joints. Under severe seismic excitations, the limited slip in joints allows considerable energy dissipation without serious permanent deformation.

Results of nonlinear dynamic analysis indicate that the use of the proposed limited-slip bolted joints, especially in vertical joints, can significantly improve the seismic performance of panel buildings.

● **6.6-14** Montgomery, C. J., **Influence of P-delta effects on seismic design,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 811-828.

The influence of P-delta effects on the response of buildings subjected to earthquake ground motion is examined. Time-history studies on the response of shear buildings to two earthquake ground motions are presented. It is shown that the influence of P-delta effects is of great importance for buildings responding in a highly inelastic manner. However, for buildings responding in an elastic or slightly inelastic manner, the influence of P-delta effects is relatively small. The stability factor approach for estimating the influence of P-delta effects is reviewed. It appears that this approach gives reasonable results only for systems responding in an elastic or slightly inelastic manner. The strength and drift characteristics of buildings are briefly described. The results presented suggest that the response of certain types of well-designed buildings will not be significantly influenced by P-delta effects.

● **6.6-15** Ishac, M. F. and Heidebrecht, A. C., **Seismic response of equipment located within asymmetric building structures,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 425-443.

This paper describes the mathematical formulation used in calculating the seismic response of equipment located within asymmetric buildings and illustrates the effect of lateral-torsional coupling of this particular class of structures on the equipment response. The equipment response is represented by floor response spectra. For the coupled analysis of asymmetric structures, the parameters of interest are the lateral floor acceleration and the rotational floor acceleration. Each floor motion time history is used as input to a series of damped single degree-of-freedom systems in order to determine the lateral and rotational floor response spectra. The response results are analyzed to determine the influence of the lateral-torsional coupling of the structure on the equipment response.

● **6.6-16** Duff, C. G. and Heidebrecht, A. C., **Earthquake fatigue effects on CANDU nuclear power plant equipment,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 325-340.

This paper presents the results of an investigation of the seismic fatigue effects on equipment located in CANDU nuclear power plants. The supporting structure and equipment are each modeled as single degree-of-freedom systems. The equipment responses are evaluated for realistic ranges of structural and equipment frequencies by subjecting the overall system to five different earthquake records. Using common material fatigué life curves, the authors devise a method to calculate the number of fatigue cycles equivalent to the total seismic response, with reference to some specific amplitude of response. This method is applied to the response results in order to determine maximum equivalent fatigue cycles for various conditions. The results are used to make recommendations for fatigue evaluation in the design of nuclear power plant equipment.

● **6.6-17** Liu, S. C. and Lin, T. H., **Elastic-plastic dynamic analysis of structures using known elastic solutions,** *Earthquake Engineering & Structural Dynamics,* 7, 2, Mar.-Apr. 1979, 147-159.

A numerical method is shown in this paper to analyze the dynamic elastic-plastic responses of those structures with known elastic solutions. The displacement at one point at time t caused by a unit load applied at another point at zero time, called the dynamic influence coefficient, is calculated from the known elastic solutions. Incremental plastic strain is accounted for by a set of additional incremental loads, so the stiffness matrix and the eigenvectors do not vary with time. From the incremental load, including that caused by the incremental plastic strain, the displacement vs. time of the structure is obtained. This method is applied to simply supported beams with bilinear stress-strain relations with different strain-hardening rates and to a simply supported elastic-ideally plastic rectangular plate. This procedure can be extended to structures with no available known analytical elastic solutions. For these structures, the elastic solutions can be obtained by the finite element method.

● **6.6-18** Dempsey, K. M. and Irvine, H. M., **Envelopes of maximum seismic response for a partially symmetric single storey building model,** *Earthquake Engineering & Structural Dynamics,* 7, 2, Mar.-Apr. 1979, 161-180.

In this paper, an analysis is made of the coupled lateral-torsional response of a partially symmetric single-story building model to horizontal translatory earthquake excitation. Interest centers on the evaluation of realistic estimates for two equivalent static actions (a shear and a torque) which account for the worst dynamic consequences

● *See **Preface**, page v, for availability of publications marked with dot.*

of torsional unbalance. The results substantiate the findings of previous investigations which have given rise to the belief that strong modal coupling and severely coupled lateral and torsional responses are possible even in nominally symmetric buildings. The response of the model is assumed to be linearly elastic and viscously damped.

In a preliminary analysis, the equations of motion are solved using the modal analysis technique. The conditions necessary for full modal coupling are ascertained. Then, by employing the design spectrum concept, together with suitably conservative procedures for combining the modal maxima, dimensionless forms of the equivalent static actions are evaluated as functions of two independent parameters. The final results are furnished by modified square root of the sum of the squares combination functions which take account of the spacing between the translational and torsional frequencies. Examples at the end of the paper illustrate the practical significance of the work.

● **6.6-19** Hawkins, N. M. and Lin, I. J., **Bond characteristics of reinforcing bars for seismic loadings,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1225-1252.

Experimental results are presented to describe the effects of loading history, bar size, concrete strength, end anchorage, joint hoop reinforcement, and bar surface geometry on the load-slip characteristics of reinforcing bars subjected to large displacements causing inelastic stress in the bars. The significance of the test results for evaluation of development length requirements for seismic-type loadings is examined, and a simple mathematical model for predicting load-slip effects is given.

● **6.6-20** Thomas, G. R. and Petalas, N., **Seismic response of shear wall-frame systems,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 989-1008.

The inelastic seismic response of shear walls coupled to frames is investigated by means of time history analyses. The effects of various wall-to-frame stiffness ratios, wall yield moments, and earthquake intensities are considered. For the configurations analyzed, yielding takes place in the lower half of the wall but the steel frame remains elastic throughout. The primary effect of yielding of the wall is to transfer loads to the frame, increasing the corresponding shear ratio above that predicted by linear static analysis. On the other hand, the change in wall moment distribution is less sensitive to inelastic action. The distribution predicted by an isolated wall static analysis is conservative, except for the case of a very flexible wall, when it is thought that higher mode contributions lead to greater moments close to the top of the wall. The values of base shear computed by inelastic dynamic analyses are in all cases considerably greater than the elastic dynamic results reduced by the appropriate system ductility factor.

● **6.6-21** Otani, S., **Nonlinear dynamic analysis of 2-D reinforced concrete building structures,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1009-1037.

This paper presents the viewpoints of the author regarding the state-of-the-art of nonlinear dynamic analysis of plane reinforced concrete building structures. The paper reviews the behavior of reinforced concrete members and their subassemblages observed during laboratory tests. Different hysteresis and analytical models of reinforced concrete members are examined. The application of these models to the simulation of the behavior of small-scale plane building models observed on earthquake simulators is discussed.

● **6.6-22** Pekau, O. A. and Gordon, H. A., **Buildings susceptible to torsional-translational coupling,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1063-1090.

Coupling between the torsional and translational responses of structures is introduced when the center of mass and the center of resistance do not coincide. The coupling is amplified when the natural frequencies in torsion and translation are close. In this paper, general guidelines are provided to identify situations in which lateral-torsional amplification may lead to potentially severe earthquake response. The effects of different building plan configurations and arrangements of lateral load-resisting elements are examined for idealized structures. The results show that buildings having uniformly distributed lateral resistance are especially susceptible to coupling, regardless of the plan configuration. A multistory frame building is studied for earthquake excitation, with special attention to the effect of closeness of frequencies in the presence of small eccentricity. It is concluded that the maximum seismic response of stiff buildings is more sensitive to coupling than that of corresponding flexible buildings, and also that occurrence of lateral-torsional coupling leads to a decrease in total base shear.

● **6.6-23** Yoshida, S. et al., **Modified substitute structure method for analysis of existing buildings,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1121-1139.

● *See **Preface,** page v, for availability of publications marked with dot.*

This paper concerns the earthquake hazard evaluation of buildings constructed prior to the most recent changes in seismic design codes. A simplified linear method is presented for predicting the behavior, including the inelastic response, of existing reinforced concrete structures with known properties and strengths when subjected to a given type and intensity of earthquake motion, as represented by a linear response spectrum. The technique involves an extension of the Shibata and Sozen substitute-structure method, which was originally proposed as a design procedure. It calculates the ductility demand of the existing members via an elastic modal analysis, in which reduced stiffness and substitute damping factors are used iteratively. By this means, it is possible to describe, in general terms, the location and degree of damage that would occur in an existing building as a result of earthquakes of different intensity. Several reinforced concrete structures of different sizes and strengths were tested by this technique, and the results are compared with a nonlinear time-step analysis. The method appears to work well for structures in which yielding is not extensive and widespread.

● **6.6-24** Otani, S., Cheung, V. W.-T. and Lai, S. S., **Behaviour and analytical models of reinforced concrete columns under biaxial earthquake loads,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1141–1167.

The effect of biaxial lateral loading on the hysteretic behavior of reinforced concrete columns is studied. No axial load was applied to the specimens in order to simplify the experiment. Three pairs of columns were tested. One column of each pair was tested under uniaxial lateral loading, while the other was tested under biaxial lateral load reversals. Diagonal cracks, flexural cracks, and crushing and spalling of shell concrete were observed on all four faces of the biaxially loaded columns. The final failure modes of a pair of specimens were similar. Loading and resulting damage in the transverse direction reduced the stiffness of a biaxially loaded column in the longitudinal direction. However, the overall hysteretic characteristics of a pair of uniaxially and biaxially loaded columns were similar. The degrading trilinear hysteresis model simulates well the hysteretic behavior of biaxially loaded columns.

● **6.6-25** Iwan, W. D. and Gates, N. C., **The effective period and damping of a class of hysteretic structures,** *Earthquake Engineering & Structural Dynamics,* **7,** *3,* May–June 1979, 199–211.

This paper presents the results of a numerical investigation in which the maximum responses of six hysteretic systems are calculated for an ensemble of twelve earthquakes. Inelastic response spectra are constructed for a range of response ductilities. An effective linear period and damping are calculated for each system and ductility by determining those parameters which minimize a root mean square response spectrum error. Conclusions are presented concerning the effects of deterioration, stiffness degradation, cracking, and ductility on the effective linear system parameters.

● **6.6-26** Cost, T. L. and Jones, H. W., **Dynamic response of blast loaded prestressed flat plates,** *Journal of Sound and Vibration,* **62,** *1,* Jan. 8, 1979, 111–120.

A finite difference method is used to study the effect of in-plane loads on the dynamic response of a square, flat plate subjected to a transverse blast load. The method can be easily programmed for rapid evaluation on a digital computer. A modal superposition method of analysis and a shock spectrum for the load are used. It is shown that in-plane tension loads significantly influence the stiffness and subsequent dynamic response of flat plates.

● **6.6-27** Rutenberg, A., **Plane frame analysis of laterally loaded asymmetric buildings-an uncoupled solution,** *Computers & Structures,* **10,** *3,* June 1979, 553–555.

In this paper, it is shown that, for a class of asymmetric building structures, a lateral load analysis can be performed by means of analogous plane frames rather than by a three-dimensional procedure. Based on a coordinate transformation, the technique is applicable to structures with two types of framing systems, each comprising several vertical planar assemblages with similar stiffness properties and a common height variation.

6.6-28 Polizzotto, C., **Upper bounds on plastic strains for elastic-perfectly plastic solids subjected to variable loads,** *International Journal of Mechanical Sciences,* **21,** *6,* 1979, 317–327.

This paper considers shakedown analysis problems for elastic-perfectly plastic solids subjected to quasi-static loads which vary arbitrarily within a given domain. A general inequality is given which is able to generate Melan's theorem for shakedown, as well as bounds on plastic strains at any point of the solid. These bounds can be made the most stringent by solving a "perturbed" shakedown problem in finite or holonomic terms. The results presented in this paper summarize those given by the author in a previous paper.

● **6.6-29** Page, A. W., **A non-linear analysis of the composite action of masonry walls on beams,** *Proceedings, The Institution of Civil Engineers,* **67,** Part 2, Paper 8185, Mar. 1979, 93–110.

A finite element model which reproduces the nonlinear behavior of masonry is described. This model considers masonry to be an assemblage of elastic brick continuum

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

elements acting in conjunction with linkage elements simulating the mortar joints. The nonlinear characteristics of the masonry are produced by the nonlinear deformation properties of the mortar and the progressive failure and/or slip that occurs in the joints when a shear or tensile bond failure criterion is violated. The model is used to predict the behavior of a brickwork wall supported by a steel beam. The results are compared with those of a conventional isotropic elastic analysis and experimental tests performed on a similar panel.

● **6.6-30** Takayanagi, T. and Schnobrich, W. C., **Nonlinear analysis of coupled wall systems,** *Earthquake Engineering & Structural Dynamics,* **7,** *1,* Jan.-Feb. 1979, 1-22.

The nonlinear response history and failure mechanism of coupled wall systems under dynamic loads and static loads are investigated using an analytical model. The walls and coupling beams are replaced by flexural elements. Axial and shear stiffnesses are included for the wall members. The stiffness characteristics of each member are determined by inelastic properties. The hysteresis loops suitable to each constituent member are established to include the specific characteristics of coupled wall systems. The computed results are compared with results obtained from tests using model structures statically and dynamically tested on an earthquake simulator.

6.6-31 Rizzo, S. and Fazio, P., **Lateral deflection of a sandwich-panel building model under combined loading,** *Experimental Mechanics,* **19,** *6,* June 1979, 193-199.

The behavior of a half-scale building model made up of modular rectangular sandwich panels and subjected to lateral and vertical loads has been analyzed experimentally and theoretically. The model was composed of 2-in.-thick sandwich panels with styrofoam core and .025-in.-thick aluminum facings stapled together with aluminum extrusions. Comparisons of the results with the design wind and seismic loads of the Uniform Building Code show the reliable structural performance of this type of structural system.

● **6.6-32** Bea, R. G., Audibert, J. M. E. and Akky, M. R., **Earthquake response of offshore platforms,** *Journal of the Structural Division, ASCE,* **105,** *ST2,* Proc. Paper 14386, Feb. 1979, 377-400.

The response and performance of conventional offshore platforms subjected to intense earthquake ground motions are of vital concern to the offshore energy industry. The platforms discussed in this paper are steel, tubular-membered, truss-framed structures supported by tubular piles and conductors. Elastic and inelastic response and platform system element characteristics are considered. An offshore platform system, if properly designed and carefully proportioned according to API RP 2A guidelines, can have earthquake resistance which equals or exceeds that of comparable conventional onshore building structures.

● **6.6-33** Asmis, G. J. K., **Response of rotating machinery subjected to seismic excitation,** *Engineering Design for Earthquake Environments,* Paper No. C192/78, 215-225. (For a full bibliographic citation, see Abstract No. 1.2-2.)

A rotating machine subjected to seismic excitation or other extreme loading events such as pipe rupture may be subjected to large gyroscopic forces. Using the CANDU (CANada Deuterium Uranium) primary heat transport pump as an example, the author examines a theoretical treatment of the phenomenon of such rotating effects. It is concluded that gyroscopically induced forces may be minimized by providing stiff, upper lateral motor supports.

● **6.6-34** Gauvain, J., Hoffmann, A. and Livolant, M., **Tests and calculations of reinforced concrete beams subjected to dynamic reversed loads,** *Engineering Design for Earthquake Environments,* Paper No. C174/78, 47-52. (For a full bibliographic citation, see Abstract No. 1.2-2.)

This study presents the tests of a reinforced concrete beam conducted by the Dept. of Mechanical and Thermal Studies at the Centre d'Etudes Nucleaires in Saclay, France. The actual behavior of nuclear power plant buildings submitted to seismic loads is generally nonlinear even for moderate seismic levels. The nonlinearity is particularly important for buildings of the reinforced concrete beam type. To estimate the safety factors when the building is designed by standard methods, accurate nonlinear calculations are necessary. Part of such calculations is the difficult task of defining a correct model for the behavior of a reinforced beam subject to reversed loads. For that purpose, static and dynamic experimental tests on a shaking table were carried out and a reasonably accurate model was established and checked against the test results.

● **6.6-35** Santhanam, T. K., **Model for mild steel in inelastic frame analysis,** *Journal of the Structural Division, ASCE,* **105,** *ST1,* Proc. Paper 14333, Jan. 1979, 199-220.

A model for mild steel is proposed for use in inelastic analysis of frames. The model is characterized by a stiffness degradation factor and a yield stress "growth" factor. These are obtained by fitting the model to results of uniaxial experiments, which are in turn used in the frame analysis program FRAME 63. The proposed material model has potential application to simulate the special features of mild steel in monotonic and reversed loadings. In one version, it represents the Masing type of inelasticity, and in another version Masing inelasticity with stiffness degradation.

● **6.6-36** Holzer, S. M., Somers, Jr., A. E. and Bradshaw, J. C., **Finite response of inelastic RC structures,** *Journal of*

● *See **Preface**, page v, for availability of publications marked with dot.*

the Structural Division, ASCE, **105**, *ST1,* Proc. Paper 14303, Jan. 1979, 17–33.

This paper is concerned with the prediction of monotonic and cyclic response histories of reinforced concrete structures by the use of computer programs. The mathematical models employed are classified to identify their distinctive features. Demonstration problems consisting of a beam, a beam column, and a frame are presented to evaluate the computer code SINGER, which is based on a one-dimensional finite element expressed in the form of an energy function. The solution process centers on function minimization. Comparisons between computed and experimental results indicate, in general, good to excellent agreement. Some discrepancies are encountered, and likely causes are cited.

● **6.6-37** Iwan, W. D. and Gates, N. C., **Estimating earthquake response of simple hysteretic structures,** *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM3,* Proc. Paper 14644, June 1979, 391–405.

This paper examines various methods for defining effective linear systems for the earthquake response analysis of simple hysteretic structures. Considered is a broad class of approximate methods, including harmonic equivalent linearization, resonant amplitude matching, dynamic mass, constant critical damping, geometric stiffness, geometric energy, stationary random equivalent linearization, and average period and damping. A technique for estimating the accuracy of different approximate methods is presented. A new linearization scheme that may be applied to both degrading hysteretic systems is proposed.

● **6.6-38** Kelly, T. E., **Floor response of yielding structures,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 107–124.

A series of inelastic computer analyses was used to obtain the maximum floor accelerations and floor response spectra for a range of low- to medium-rise buildings responding to earthquake loadings. From the results, tentative equations for the design of building components and services are proposed. The maximum floor accelerations are shown to be a function of the yield level of the structure, the maximum ground acceleration, and the floor level. The floor accelerations are further amplified by flexible components, this amplification being markedly affected by higher building modes and by component damping.

● **6.6-39** Youssef, N. A. N. and Popplewell, N., **The maximax response of discrete multi-degree-of-freedom systems,** *Journal of Sound and Vibration,* **64**, *1,* May 8, 1979, 1–15.

Estimates of the maximax displacements of multidegree-of-freedom rather than single degree-of-freedom systems to incompletely described loads are shown to be reasonable. The conventional approach to designing a constant tuned vibration neutralizer appears justifiable even though it does not produce a truly optimum solution.

● **6.6-40** Townsend, W. H., **Inelastic response of interior R/C connections with slab,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 493–511.

Five full-scale interior beam-column connections, tested with eleven cycles of inelastic loading, developed about 65 percent of the ultimate moment capacity of the subassemblage. Two of the connections constructed with the beam steel running diagonally through the column developed 25 percent more joint core shear than the standard connections. The inelastic loading sequence used produced a loss of joint core shear of about 40 percent. Most of this loss occurred in the concrete; almost none occurred in the steel hoops.

● **6.6-41** Ma, D., Leonard, J. and Chu, K.-H., **Slack-elastoplastic dynamics of cable systems,** *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM2,* Proc. Paper 14508, Apr. 1979, 207–222.

A numerical procedure is presented for determining the nonlinear dynamic response of cable systems in which cable segments may be included as elastic, plastic, or buckled (slack) elements. Individual cable elements in the network are assumed either elastic, plastic, or slack, depending on the time history of load and system response. Finite element analogs are used as the basis for numerical modeling for spatial behavior. The equations of motion were derived from the nonlinear Hamilton principle and linearized incrementally to approximate the true behavior within each load or time increment. A curved element is adopted which maintains slope continuity between cable segments, and isoparametric displacement functions are adopted. The Newmark B method is used as the basis for the numerical integration for the temporal behavior.

● **6.6-42** Itani, R. Y., **Elasto-plastic torsion of axisymmetric bars,** *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM1,* Proc. Paper 14367, Feb. 1979, 1–12.

A numerical approach for solving the elastoplastic torsion problem of axisymmetric bars is presented. The method uses finite elements and a minimum rate principle of plasticity to provide a complete stress history under the action of a quasi-static, monotonically increasing angle of twist. The use of finite elements and a stress function formulation reduces the minimum rate principle to a quadratic programming problem. The method is shown to

● *See **Preface**, page v, for availability of publications marked with dot.*

be suitable for general applications and to provide good comparisons with available solutions.

● 6.6-43 Symonds, P. S. and Chon, C. T., **Large viscoplastic deflections of impulsively loaded plane frames**, *International Journal of Solids and Structures*, **15**, *1*, 1979, 15-31.

Applications are described of two estimation techniques to obtain final deflections and response times of plane rectangular frames subjected to impulsive loading on the transverse (beam) member. Deflections up to roughly one third the span (30 thicknesses) are estimated by the mode approximation and deflection bounds techniques, treating the plastic rate dependence by means of homogeneous viscous constitutive equations. Comparisons are made with recent test results, and the degree of agreement is discussed in terms of the known error sources of the two techniques.

● 6.6-44 Bodner, S. R. and Symonds, P. S., **Experiments on dynamic plastic loading of frames**, *International Journal of Solids and Structures*, **15**, *1*, 1979, 1-13.

This paper describes tests on plane frames of mild steel and titanium (commercial purity) in which high-intensity short-duration pressure pulses were applied transversely to the beam member either uniformly over the member or concentrated at its center. The objective was to examine applications of two estimation techniques (upper bounds on deflections and the mode approximation technique) for major response features of pulse-loaded structures at large deflections, taking account of strong plastic strain rate sensitivity. Loads over a range such as to cause final deflections up to about a third of the span were applied by detonating a sheet explosive. Agreement between estimated and measured final deflections was often very good (generally conservative) but the intrinsic error of the mode technique was not observed as expected.

● 6.6-45 Nath, Y., **Non-linear dynamic response of rectangular plates subjected to transient loads**, *Journal of Sound and Vibration*, **63**, *2*, Mar. 22, 1979, 179-188.

The nonlinear dynamic responses of clamped and simply supported rectangular plates are investigated for uniform pulse loadings. The nonlinear partial differential equations are linearized by expressing one or more of the product terms constituting the nonlinearity in the differential equations in Taylor's series. By using a finite difference method for space-wise integrations and the Houbolt method for time-wise integrations, the differential equations are transformed into a set of linear algebraic equations solved by matrix methods without using any iterative techniques. The numerical results obtained by the technique compare well with the results available in the literature. In addition, the influence of damping on the nonlinear dynamic response is studied.

● 6.6-46 Ariman, T. and Muleski, G. E., **Recent developments in seismic analysis of buried pipelines**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 643-652.

This paper reviews recent developments in the seismic analysis of buried pipelines. Because of the great potential for damage and disruption, the problems of utility systems subjected to earthquakes have recently attracted researchers and engineers. It has become apparent that the seismic behavior of buried pipeline systems is quite different than that of above-ground structures. It is hoped that the present review will provide additional stimulus for further investigations in this important area.

● 6.6-47 Jain, A. K. and Goel, S. C., **Cyclic end moments and buckling in steel members**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 413-422.

This paper presents a new hysteresis model for steel members which accounts for the reduction in compressive strength in the first two cycles, the increase in member length, and the effects of end moments. This model is called the "end moment-buckling element" for use with the DRAIN-2D computer program.

● 6.6-48 Huckelbridge, Jr., A. A. and Christ, R. A., **Nonlinear overturning effects in a core-stiffened building**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 403-412.

A number of experimental and analytical studies have demonstrated the dynamic stability and the reduced lateral loading-ductility requirements associated with allowing transient uplift of portions of a structure during extreme seismic response. Verification of nonlinear analysis capabilities has also been accomplished. There is, however, a scarcity of data describing the nonlinear overturning response of the various structural systems currently in popular usage. In addition, there are available relatively few design details intended to accommodate transient uplift response without foundation or superstructure damage. This paper presents analytical data describing the nonlinear overturning response of one such structure, a 20-story, core-stiffened, reinforced concrete structure. Also described are design details to accommodate the transient uplift of the core from the foundation during seismic response. Comparisons are made between the uplift response and the conventional fixed-base response.

● 6.6-49 Perdikaris, P. C., Conley, C. H. and White, R. N., **Shear stiffness degradation of tensioned reinforced concrete panels under reversing loads**, *Proceedings of the*

● *See **Preface**, page v, for availability of publications marked with dot.*

2nd U.S. National Conference on Earthquake Engineering, Earthquake Engineering Research Inst., Berkeley, California, 1979, 175–184.

This paper presents experimental data on the effects of cyclic membrane shear loading, biaxial tension, and reinforcement ratio upon the degradation of shear stiffness and strength of biaxially tensioned reinforced concrete specimens under fully reversing cyclic shear loads. The specimen configuration and the loading scheme employed were chosen to best simulate the membrane stress state in the wall of a nuclear containment vessel under combined internal pressurization plus shear loads caused by seismic forces. Flat specimens reinforced in a two-way orthogonal pattern were subjected to biaxial tension and fully reversing in-plane membrane shear loads. Parameters studied included the applied axial tension in the reinforcement, the reinforcement ratio, and the type (cyclic or monotonic) and level of applied shear stress.

● **6.6-50** Clough, R. W. and Ghanaat, Y., **Seismic behavior of diagonal steel wind bracing,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 313–322.

The purpose of this study was to obtain experimental data on the seismic performance of a building frame with diagonal wind bracing and to correlate these results with computer analyses. The tests were performed using the 20-ft-square earthquake simulator facility at the Earthquake Engineering Research Center, Univ. of California, Berkeley. The basic test structure was a three-story steel building frame which had been used in previous studies. Diagonal rod bracing, supplied originally to control lateral or torsional motions of the frame, was made the subject of the present research by mounting the structure on the shaking table at 90° to its previous orientation. In addition to the original rod bracing system, welded pipe X-bracing also was studied in this investigation. Results of the tests and correlation of the test results with analytical predictions are described in this paper.

● **6.6-51** Gergely, P. and Smith, J. K., **Seismic response of cracked cylindrical concrete structures,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 185–192.

Wall-type reinforced concrete structures built in seismic zones must often be able to transmit seismic shear forces across cracks. The mechanism includes interface shear transfer of concrete and dowel action of reinforcement. The most significant examples are such structures as reinforced concrete nuclear containment shells and offshore gravity structures. In containment shells, the cracks may be caused by internal pressure; in offshore structures, by seismic or wave forces. Sliding occurs along horizontal cracks during seismic excitation. In containment shells, vertical cracks may also develop as a result of internal pressurization, which further reduces the shear stiffness of the structure. The overall and local dynamic deformations, the maximum slip at cracks, and the shear stresses are important design parameters. These quantities were studied by means of nonlinear dynamic analyses; the results are briefly described.

● **6.6-52** Becker, J. M. and Llorente, C., **The seismic response of simple precast concrete panel walls,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 423–432.

This paper explores through a series of analytical studies the possible influence of rocking and slipping phenomena on the seismic response of simple precast concrete walls. A finite element approach is used in which all nonlinear inelastic behavior is concentrated in the connection elements. The paper also reports on parametric studies of 5- and 10-story walls with various reinforcement patterns for providing vertical continuity.

● **6.6-53** Werner, S. D. and Lee, L. C., **The three-dimensional response of structures subjected to traveling Rayleigh wave excitation,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 693–702.

This paper examines the influence on the three-dimensional response of a simple bridge structure of spatially varying excitations associated with Rayleigh waves. The work was motivated by two main factors. First, there is growing evidence that surface waves, including Rayleigh and Love waves, have had a major influence on the low- and intermediate-frequency components of ground shaking recorded during several earthquakes, such as the Imperial Valley (1940), Parkfield (1966), and San Fernando (1971) events in California. Second, very few studies of Rayleigh wave excitations have been made, and these studies have generally been based only on simple structural elements such as a single rigid, rectangular foundation or on a single spring–mass oscillator on a rigid foundation. Nevertheless, the studies have provided insights into such Rayleigh wave effects as (a) the rocking motions generated by Rayleigh waves that are normally incident to one of the sides of a rectangular foundation; and (b) the three-dimensional response characteristics generated by obliquely incident Rayleigh waves. The potential importance of such response characteristics underscores the need to study Rayleigh wave effects further, using a more refined model of a three-dimensional, deformable structure of extended length.

● **6.6-54** Popov, E. P., **Inelastic behavior of steel braces under cyclic loading,** *Proceedings of the 2nd U.S. National*

Conference on Earthquake Engineering, Earthquake Engineering Research Inst., Berkeley, California, 1979, 923–932.

Results of 24 experiments on steel members loaded cyclically into the inelastic range are described and evaluated. Because the specimens tested were larger than those tested in the past, it was possible to use structural rolled shapes employed in practice and to simulate the geometries of larger members.

● **6.6-55** Kircher, C. A. et al., **Performance of a 230 KV ATB 7 power circuit breaker mounted on Gapec seismic isolators,** *Report 40,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Sept. 1979, 24.

The 230 KV ATB 7 power circuit breaker structure described in this report, modified by the addition of Gapec seismic isolators, exhibited the following behavior during dynamic testing. (1) The natural frequencies of the modified breaker structure are the same for the longitudinal and transverse directions. The fundamental frequency is in the range of 0.73 Hz to 1.05 Hz, depending on the stiffness of the isolators used. (2) The damping in the modified breaker structure (regardless of isolator stiffness) is approximately 4%. (3) The fundamental mode shape indicates that the breaker structure responds almost entirely as a rigid body. Therefore, no substantial bending takes place in the porcelain insulators in this mode. (4) Comparison of the modified breaker structure with the unmodified structure shows that the modified breaker structure has a fundamental frequency which is lower by a factor of at least 2.6. The damping ratio for the modified structure is approximately 4.5 times higher than for the unmodified structure. Consequently, the response accelerations, base shears, and overturning moments in the modified breaker structure (as determined by the California Dept. of Water Resources response spectrum for a 0.5 g ground motion) are calculated to be a factor of between 4 and 5 lower than the corresponding calculated responses in the unmodified breaker structure, depending on the stiffness of the isolators used.

It appears that the installation of Gapec isolators substantially reduces the level of response of the 230 KV ATB 7 circuit breakers for a given input ground motion spectrum. It can be concluded that the Gapec isolators should provide a better protection for circuit breakers against seismic damage.

● **6.6-56** Irvine, H. M. and Kountouris, G. E., **Inelastic seismic response of a torsionally unbalanced single-story building model,** *Publication R79-31, Seismic Behavior and Design of Buildings Report 2,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, July 1979, 163.

An investigation of the inelastic seismic response of a simple torsionally unbalanced building is reported in this paper. The studies concern a two degree-of-freedom model in which two frames support a diaphragm in which the center of mass may be offset from the center of stiffness. The frames are assumed to behave as simple elastic-plastic springs and to have the same stiffness and strength levels. A comprehensive parametric study is undertaken in an attempt to identify trends in the peak ductility demands of the most poorly situated frame which is frequently, although not always, the one nearest the center of mass. The results are discussed and presented in an extensive series of plots. A simple frequency domain analysis is outlined in an attempt to explain why the peak ductility demands sometimes occur in the frame farthest from the center of mass. It is concluded that the most important parameter is one involving the product of diaphragm mass and spectral acceleration normalized by a yield level in the frame. For wide ranges of the other parameters, the peak ductility demand is roughly linear in this parameter—a result well known for symmetric structures. Surprisingly, eccentricity does not appear to be a particularly significant parameter. Regression analysis is performed to yield simple confidence levels for the peak ductility demands.

● **6.6-57** Gluck, J., Reinhorn, A. and Rutenberg, A., **Dynamic torsional coupling in tall building structures,** *Proceedings, The Institution of Civil Engineers,* Part 2, **67,** Paper 8203, June 1979, 411–424.

Using a single-story torsional coupling analogy, the paper shows how and under what conditions the existing approaches to the dynamic analysis of asymmetric tall buildings can be applied to a wide class of irregular structures. A step-by-step procedure using the response spectrum technique is outlined and illustrated by a numerical example. A three-dimensional rather than a two-dimensional formulation is adopted to emphasize the generality of the approach. The discrete and distributed parametric formulations are followed throughout the mathematical exposition.

● **6.6-58** Popov, E. P., Zayas, V. A. and Mahin, S. A., **Cyclic inelastic buckling of thin tubular columns,** *Journal of the Structural Division, ASCE,* **105,** *ST11,* Proc. Paper 14982, Nov. 1979, 2261–2277.

Experimental results are described of the cyclic inelastic buckling of one-sixth-scale thin tubular steel columns typical of braces employed in fixed offshore platforms. Six 4-in. (102-mm) diameter tubes were tested. Tube diameter-to-wall thickness (D/t) and slenderness ratios considered are typical of those used in practice. The D/t ratio was 33 for three specimens and 48 for the other three. In each group of three, two had pinned ends and one had fixed ends. All specimens were annealed, except for one of the pin-ended specimens in each group that was tested in the

● *See **Preface**, page v, for availability of publications marked with dot.*

condition as received. Hysteresis loops for the applied axial force versus axial deformation, as well as versus the maximum lateral deflection, are presented and interpreted. Based on these data, suggestions are made for analytic (computer) representations of such loops for use in seismic response analyses of braced offshore towers.

● **6.6-59** Gesund, H. and Goli, H. B., **Limit analysis of flat-slab buildings for lateral loads,** *Journal of the Structural Division, ASCE,* **105,** *ST11,* Proc. Paper 14981, Nov. 1979, 2187–2202.

The flexural strength of multistory flat-slab buildings subjected to combined vertical and horizontal (sidesway) loadings is investigated by inelastic theory. It is postulated that the columns will be made strong enough so that failure will occur in the slabs. Yield-line theory is used to determine the flexural strength of the slab-column joints and to analyze the overall flexural collapse mechanisms of the slabs when the structure is subjected to the combined loadings. Equations and graphs are presented that will facilitate the limit design of orthotropically reinforced slabs against sidesway-type flexural failure of both the slab-column joints and the overall slab structure. The bending moments for which the columns must be designed are also obtained in the course of the slab-design process.

● **6.6-60** Anagnostopoulos, S. A., **Post-yield flexural properties of tubular members,** *Journal of the Structural Division, ASCE,* **105,** *ST9,* Proc. Paper 14821, Sept. 1979, 1757–1768.

In order to carry out inelastic dynamic analyses of steel offshore platforms under earthquake excitations, flexural members are generally modeled by assuming the formation of plastic hinges at the ends when the corresponding moments exceed a limiting value. In this work, static solutions are obtained for the yield and post-yield properties of tubular members in flexure by making use of experimental moment-curvature relationships that are available in nondimensional form for several levels of axial load acting on the section. The objective is to determine improved properties for the point hinges by considering the spread of yielding. These properties are the equivalent yield moment at zero axial load, the post-yield stiffness expressed as a fraction of the corresponding elastic stiffness, and an interaction diagram giving the yield moment as a function of the axial load. The sensitivity of response to variations in these properties is also examined by analyzing an example platform.

● **6.6-61** Gomes de Oliveira, J. and Jones, N., **A numerical procedure for the dynamic plastic response of beams with rotatory inertia and transverse shear effects,** *Journal of Structural Mechanics,* **7,** *2,* 1979, 193–230.

A numerical procedure is used to examine the influence of transverse shear forces in the yield criterion and rotatory inertia on the dynamic plastic response of beams. Various results are presented for a long beam impacted by a mass and a simply supported beam loaded impulsively, both of which are made from a rigid perfectly plastic material with yielding controlled by the Ilyushin-Shapiro yield criterion. Transverse shear effects lead to a dramatic reduction in the slopes of the deformed profiles for both beam problems. Moreover, the slope of the deformed profile underneath the striker in the impact problem is quite sensitive to the actual shape of a yield curve, while the maximum transverse displacement is less sensitive. The retention of rotatory inertia in the basic equations leads to further reductions up to 17 and 10% in the slopes and maximum transverse displacements, respectively.

● **6.6-62** Capurso, M., **Some upper bound principles to plastic strains in dynamic shakedown of elastoplastic structures,** *Journal of Structural Mechanics,* **7,** *1,* 1979, 1–20.

Suitable measures of plastic strains after adaptation (shakedown) of elastoplastic continuous structures subjected to dynamic loading are shown to be bounded from above by quantities which can be evaluated on the basis of a linear elastic response of the body to prescribed initial conditions. The results achieved are extended to elastic work-hardening bodies under the assumption of a piecewise linear yield surface. The practical use of the results is checked by application to a simple example.

● **6.6-63** Jones, N. and Gomes de Oliveira, J., **The influence of rotatory inertia and transverse shear on the dynamic plastic behavior of beams,** *Journal of Applied Mechanics, ASME,* **46,** 2, June 1979, 303–310.

The theoretical procedure presented examines the influence of retaining the transverse shear force in the yield criterion and rotatory inertia on the dynamic plastic response of beams. Exact theoretical rigid perfectly plastic solutions are presented for a long beam impacted by a mass and a simply supported beam loaded impulsively. It is found that rotatory inertia might play a small, but not negligible, role in the response of these beams. The results in the various figures indicate that the greatest departure from an analysis which neglects rotatory inertia but retains the influence of the bending moment and transverse shear force in the yield condition is approximately 11 percent for the particular range of parameters considered.

● **6.6-64** Wolf, J. P. and Skrikerud, P. E., **Collapse of chimney caused by earthquake or by aircraft impingement with subsequent impact on reactor building,** *Nuclear Engineering and Design,* **51,** *3,* Feb. 1979, 453–472.

● *See **Preface,** page v, for availability of publications marked with dot.*

The behavior is examined of a typical chimney stack of a nuclear power plant subjected to earthquake and impact loads. The explicit integration procedure using convected coordinates is adopted to perform the transient analyses with large displacements and material nonlinearities of the concrete stack, of the impinging aircraft, and of the soil. Because of the favorable effect of the partial separation of the base mat from the soil (lifting-off), the chimney does not collapse for realistic accelerations of the earthquake. Force-time relationships of the aircraft impinging on the chimney are developed. The impact of aircraft debris causes only local damage of the chimney. The direct impingement of an aircraft, however, may lead to partial collapse or total overturning of the chimney. The resulting motion, including the impact of the chimney on the reactor building, is studied. The response of the structure being hit, and of the equipment located within, will in many cases govern their design.

● **6.6-65** Lopez, O. A. and Chopra, A. K., **Gravity load and vertical ground motion effects on earthquake response of simple yielding systems,** *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM4,* Proc. Paper 14735, Aug. 1979, 525–538.

The computed responses of idealized single-story yielding systems to earthquake ground motion are presented with the objective of evaluating the effects of gravity loads and vertical ground motions. The results demonstrate that the coupling between lateral and vertical deformations created by yielding in the system must be considered in order to predict the plastic part of vertical deformation caused by horizontal ground motion. However, a simpler analysis without such deformation coupling, but with a reduction of lateral yield strength resulting from the gravity load, would generally be satisfactory for predicting the lateral response of the system. The principal effect of the vertical component of ground motion is to superpose elastic vertical oscillations about the gradually growing vertical deformation that results from yielding caused by horizontal ground motion alone.

● **6.6-66** Coull, A. and Low, C. K., **Analysis of stiffened non-planar coupled shear walls,** *Proceedings, The Institution of Civil Engineers,* Part 2, **67**, Paper No. 8255, Dec. 1979, 971–986.

Based on Vlasov's theory of thin-walled beams and the continuous medium technique, an approximate method is presented for the analysis of nonplanar coupled shear walls subjected to lateral loads which produce combined bending and torsional deformations. Particular attention is given to the case where the structure is reinforced by an additional stiffer connecting beam at roof level. This induces additional axial forces and thus reduces the wind moments in the walls as well as helping to reduce warping deformations. The omission of St Venant's torsional constant allows the solution to be simplified with little loss of accuracy. The accuracy of the solution is checked by comparison of the theoretical results with those from tests on 18-story models of different cross-sectional shapes.

● **6.6-67** Zakic, B. D., **Wood beams under impact load,** *Journal of the Structural Division, ASCE,* **105**, *ST7,* Proc. Paper 14690, July 1979, 1489–1507.

An analysis of the behavior of glue-laminated wood beams under impact loads in the elastic and plastic ranges is presented. The theoretical part of the study consists of the definition of the general methodology of solving the vibration of the system with a nonlinear ratio between force and deformations. The validity of the vibration design is verified by a testing program using full-sized specimens. The test results agree favorably with the theoretical predictions. There is good coincidence in the elastic range between the actual and theoretical dynamic characteristics. There is a discrepancy between measured deformations under static and dynamic loads in the plastic range. The theoretical dynamic characteristics, with and without damping, coincide well with the corresponding real dynamic characteristics. The theoretical method given may be used in the plastic range.

● **6.6-68** Hays, Jr., C. O. and Santhanam, T. K., **Inelastic section response by tangent stiffness,** *Journal of the Structural Division, ASCE,* **105**, *ST7,* Proc. Paper 14668, July 1979, 1241–1259.

The inelastic analysis of a cross section is reviewed. Given the history of deformation, the history of axial force and moment may be obtained. Conversely, given the history of moment and axial force, the history of deformation may be obtained. The tangent stiffness method is modified to avoid convergence difficulties caused by "large" inelastic unloading. The stress-strain curves considered are generally nonlinear but symmetric, exhibiting hysteresis and the Bauschinger effect. The solution is checked against other solutions. The method has been included in a discrete element frame analysis program and used to predict the behavior of a brace member for which experimental results are avilable.

● **6.6-69** Gerwick, B. C. and Venuti, W. J., **High-and-low-cycle fatigue behavior of prestressed concrete in offshore structures,** *Proceedings of Eleventh Annual Offshore Technology Conference–1979,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3381, 1979, 207–214.

The continuing use of prestressed concrete in offshore structures in hostile environments has generated intense interest in the fatigue endurance capabilities of the concrete, even though, as far as it is known, no fatigue problems have occurred in actual structures. Although concrete does suffer a progressive loss of strength with an increasing number of cycles, a comparison of the Wohler curves developed on the basis of laboratory tests with the probable distribution of compressive stresses during a service life in an environment such as the North Sea shows extremely low cumulative usage at the high-cycle end of the spectrum. However, significant damage can occur at the low-cycle, high-amplitude end of the spectrum under a relatively small number of cycles of very high magnitude. This damage is displayed by a reduction in stiffness and by rapidly increasing axial and lateral strains that lead to cracking and spalling. Repeated cycling into high compressive ranges causes a substantial increase in creep, reducing the effective prestress. Confining reinforcement resists lateral deformation and delays compressive fatigue failure.

Many cycles into the tensile range can produce cracking because of tensile fatigue at about half the static tensile strength. Cracking also can occur because of overload, accident, construction procedures, and thermal strains. Repeated excursions of submerged concrete into the crack opening range lead to the pumping of water in and out of the crack and hydraulic wedging, in turn causing the concrete to split. Cracking subjects the reinforcing and prestressing steel to cyclic tension. Loss of bond ensues and may lead to eventual fatigue failure. This condition may be adequately offset by the provision of adequate percentages of steel across the section and by the provision of transverse and confining steel. Cyclic shear may produce diagonal tension cracking at about half the static strength. Conventional reinforcing in an orthogonal grid pattern is very inefficient for resisting such cracking. Crack widths grow rapidly. Repeated loading may lead to abrasion of concrete surfaces and failure of the steel because of combined axial force and bending. Vertical prestress is an efficient and practical method of resisting high-amplitude cyclic shear. For the typical concrete sea structure, high-cycle cumulative fatigue is not a significant problem. However, low-cycle, high-amplitude fatigue requires consideration, especially when there are numerous cycles into the tensile cracking range. In this latter case, fatigue of the steel or concrete may occur unless adequate amounts of steel are provided to ensure that crack widths and steel stresses are kept within allowable values.

● **6.6-70** Kawai, T. and Toi, Y., **A discrete analysis on dynamic collapse of clamped beams and rectangular plates loaded impulsively**, *Bulletin of Earthquake Resistant Structure Research Center,* **12**, Mar. 1979, 57–64.

In previous papers by the authors, a new discrete method was proposed for analyzing the dynamic collapse of beams and plates subjected to transverse impulsive loads. In this paper, the method is applied to the dynamic collapse analysis of clamped beams and rectangular plates under distributed impulsive loading. Numerical results obtained are compared with experimental results obtained by N. Jones in order to verify the validity of the present method.

● **6.6-71** Takizawa, H. and Jennings, P. C., **Collapse of a model for ductile reinforced concrete frames under extreme earthquake motions** [California Inst. of Technology, Pasadena], 1979, 52.

A mathematical formulation is presented in this paper for modeling the dynamic process of failure for a class of ductile, moment-resisting, reinforced concrete frame buildings subjected to intense earthquake motion. The formulation includes the geometrically nonlinear term that accounts for the destabilizing action of gravity. In many cases of practical interest in which the structures have strong columns and weak girders, the employed method of synthesizing the restoring force properties can provide a satisfactory description of the structural deformation at large deflections. By modeling approximately the effects of gravity, cracking, yielding, and degradation of stiffness, the study aids in understanding the process of failure in this type of ductile R/C structure, and relates the mechanics of collapse to characteristics of the excitation. The collapse of R/C frames having strong girders and weak columns which can develop sway mechanisms at a single story is not considered in this study. Special examination is made of the capacity to resist short-duration motions consisting of a few pulses versus the capacity to resist motions of longer duration. For the class of structures modeled, the results indicate an extremely low destructive capability associated with short-duration motions, even when they have very high accelerations. The application in research of a two-parameter characterization of the severity of ground motion in terms of intensity and duration is also examined.

● **6.6-72** Subrahmanyam, B. V., **Prediction of the inelastic behavior of one-way continuous slabs**, *Journal of the American Concrete Institute,* **76**, 5, Title No. 76-28, May 1979, 621–634.

One-way continuous slabs designed according to the redistributions permitted by ACI 318 have considerable reserve load-carrying capacity because of their large plastic rotation capacities. Methods are necessary for reliable prediction of the behavior of one-way continuous slabs so that a more realistic and economical design basis can be developed. This paper reports on tests on two-span continuous slabs designed with different degrees of redistribution. Utilizing the results of these tests and tests reported in literature, it is established that trisegmental M-ϕ relations give excellent predictions of the inelastic behavior of one-way continuous slabs at all the limit states (deflection, crack width, and plastic rotation compatibility). In contrast, bilinear relations and constant stiffness assumption give poor and even unsafe predictions and hence are shown to be unreliable.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● **6.6-73** Shipman, J. M. and Gerstle, K. H., **Bond deterioration in concrete panels under load cycles,** *Journal of the American Concrete Institute,* **76,** *2,* Title No. 76-16, Feb. 1979, 311-325.

Serious discrepancies have been observed between the predicted and measured responses of reinforced concrete panels subjected to load reversals. It was hypothesized that these differences might be attributed to the neglect of bond-slip between steel and concrete in the earlier analysis. To investigate this hypothesis, the bond-slip behavior between steel and concrete is described, based on earlier experimental and analytical studies, and incorporated into a finite element program. The results of this analysis, including bond-slip, are compared to earlier test results and appear to account for a fraction of the difference in response. The possibility that the remaining difference might be accounted for by including the deterioration of concrete under load cycles is noted.

● **6.6-74** Rutenberg, A., **A consideration of the torsional response of building frames,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, 11-21.

The history of elastic static procedures for the seismic analysis of torsionally unbalanced building structures is briefly reviewed. It is suggested that the provisions of NZS 4203:1976, which account for modal coupling, are based on inconsistent interpretation of results from well-known two degree-of-freedom models. An alternative dynamic procedure is described which, while retaining the basic two-dimensional features of the NZS 4203:1976 torsional provisions, is equivalent to three-dimensional modal spectral analysis. The procedure also results in a substantial simplification of the analysis compared with standard dynamic computer techniques now available to the structural engineer.

● **6.6-75** Roehl, J. L. P., **Dynamic response of ground-excited building frames,** Univ. Microfilms International, Ann Arbor, Michigan, 1979, 126.

The objective of this investigation is to thoroughly evaluate the nonlinear dynamic behavior of relatively simple multistory building frames with flexible girders subjected to transient ground excitations. An assessment is planned of the most important factors affecting the response of such systems. Information and concepts will be developed whereby the significant aspects of the nonlinear response of multistory building frames may be estimated by simplified analyses.

● **6.6-76** Soleimani, D., Popov, E. P. and Bertero, V. V., **Hysteretic behavior of reinforced concrete beam-column subassemblages,** *Journal of the American Concrete Institute,* **76,** *11,* Title No. 76-48, Nov. 1979, 1179-1195.

This paper describes an experimental investigation of the behavior of two reinforced concrete cruciform beam-column subassemblages under simulated seismic loadings. The half-scale specimens used in the study modeled a part of a ductile reinforced concrete frame for a 20-story building at the third-floor level. Because of the poor bond of the main bars created by instrumentation within the interior joint for one of the specimens, premature anchorage failure was observed. This kind of behavior, which may occur in practice because of poor workmanship, is compared with the behavior of a specimen with beam bars having full anchorage within the joint. For the latter case, a comparison between experimental results and analytic predictions is made. By including the beam fixed-end rotations and the inelastic behavior of beams along their lengths, good agreement between experimental and analytical results is obtained.

● **6.6-77** Morita, S. and Kaku, T., **Splitting bond failures of large deformed reinforcing bars,** *Journal of the American Concrete Institute,* **76,** *1,* Title No. 76-5, Jan. 1979, 93-110.

Tests have been carried out to study splitting bond failures of large bars having a nominal diameter of 51 mm (2 in.) and various deformation patterns. The test setup, referred to as the modified cantilever type, permits the development of a stress distribution in the test specimen similar to that found in the shear span of beams. The main variables studied were clear cover; number of stirrups; bond/shear ratio; loading history, including alternating pull-out; push-in loads; and bar deformation. Based on the test results, recommendations are provided for the application of large bars to the design of earthquake-resistant framed structures.

● **6.6-78** Seki, M. and Okada, T., **Nonlinear earthquake response of reinforced concrete building frames by computer-actuator on-line system (Part V: analysis by equivalent linear model and conclusion)** (in Japanese), *Transactions of the Architectural Institute of Japan, 284,* Oct. 1979, 79-84.

This paper is the last in a five-part series and consists of two sections. In the first section, an equivalent linear model is proposed to develop a simpler analytical model than those models used in the computer program OS-1D in the previous papers. The proposed model consists of (1) a tetra-linear skeleton curve having an origin-oriented hysteretic rule and (2) an equivalent viscous damping ratio which depends upon the observed maximum response displacement in terms of the ductility factor. It is found that the proposed model analysis can simulate well the maximum response displacement obtained by the on-line test. In the second section, the results of the entire project are summarized.

● *See **Preface,** page v, for availability of publications marked with dot.*

● **6.6-79** Fujiwara, T., **Earthquake response of framed structures having aseismic elements (Part I)**, *Transactions of the Architectural Institute of Japan, 285*, Nov. 1979, 101-108.

In this report, the hysteretic characteristics of an X-type brace supported by two hinges with an elastoplastic joint at the middle of the brace are formulated. The hysteretic characteristics of an inelastic brace, with the yield condition and flow rule considered, are also examined. A method of earthquake response analysis of elastoplastic braced frame structures is then formulated.

● **6.6-80** Ueda, S. and Shiraishi, S., **Observation of oscillation of a deep water platform and the ground during earthquakes,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3614, 1979, 2225-2234.

In this paper, the vibrational characteristics of a deepwater platform with vertical and oblique piles are discussed. This type of structure is subjected to loads from waves, winds, and earthquakes. In seismic zones such as Japan, earthquake loading is important in determining structural dimensions. Although many deepwater platforms have been constructed, there are no earthquake records with which to evaluate the earthquake-resistant design of deepwater terminals. The platform discussed in this paper is a 200,000 DWT oil tanker terminal with oblique piles presently operating in Kashima, Japan. The platform is supported by 10 vertical and 8 oblique piles. Three sensors are set in the ground and four are set on the platform. Six earthquake records obtained since Mar. 1978 are analyzed and the dynamic response characteristics of the platform are examined. Frequency spectra and response spectra are produced from the data. A multi-node nonlinear computation program is developed. The earthquake responses of a pile foundation platform or a jacket-type platform are calculated. Theoretical results and observed data are compared.

● **6.6-81** Adriani, L. and Franciosi, V., **Automatic calculation of frames: a utilization of the programmable pocket computers with magnetic cards** (Il calcolo automatico dei telai: una utilizzazione dei calcolatori programmabili portatili a schede magnetiche, in Italian), *Giornale del genio civile,* **117**, *4-6*, Apr.-June 1979, 155-167.

● **6.6-82** Ottazzi, G. and Bariola, J., **Inelastic test of a single-story structure during the earthquake of October 3, 1974, in Lima** (Respuesta inelastica de una estructura de un piso durante el sismo del 3 de octubre de 1974 en Lima, in Spanish), *DI-78-03,* Dept. de Ingenieria, Pontificia Univ. Catolica del Peru, Lima, 1978, 17. (Paper originally presented at the 19th Jornadas Sudamericanas de Ingenieria Estructural, Santiago, 1978.)

This work analyzes a single-story reinforced concrete structure which partially collapsed in the Lima earthquake of Oct. 1974. The theoretical behavior of this structure is studied and then the theoretical model is subjected to excitation caused by several earthquakes to determine the step-by-step dynamic response. Conclusions and recommendations are given for future design and construction in this zone.

● **6.6-83** Saiidi, M. and Sozen, M. A., **Simple and complex models for nonlinear seismic response of reinforced concrete structures,** *UILU-ENG-79-2013, Structural Research Series 465,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, Aug. 1979, 188.

The object of this study was to simplify the nonlinear seismic analysis of reinforced concrete structures. The work consisted of two independent parts. The first was to study the influence of calculated responses to hysteresis models used in the analysis, and to determine whether satisfactory results could be obtained using less complicated models. For this part, a multidegree-of-freedom analytical model was developed to work with three hysteretic systems previously proposed in addition to two systems introduced in this report. The results of experiments on a small-scale, ten-story reinforced concrete frame were compared with the analytical results using different hysteretic systems. In the other part of the study, an economical, simple single degree-of-freedom model was introduced to calculate nonlinear displacement-response histories of structures.

● **6.6-84** Jain, A. K. and Goel, S. C., **Seismic response of eccentric and concentric braced steel frames with different proportions,** *UMEE 79R1,* Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, July 1979, 88.

This paper examines the influence of different member proportions on the seismic response of braced frames. A 7-story structure is used in this study to limit computation cost. Two types of bracing patterns are studied: eccentric split K and concentric K. The response of these bracing patterns is examined under the May 1940 El Centro ground motion and an artificially generated B1 accelerogram.

Three 7-story, single-bay, eccentrically braced split K-frames were analyzed under these two ground motions. These frames had weak girder-strong brace, weak girder-intermediate brace, and strong girder-weak brace member proportions. Recommendations for selecting an appropriate hysteresis model for bracing members in a given situation are given.

Three 7-story, single-bay, concentrically braced K-frames were also analyzed under the same ground motions. These frames had weak girder-intermediate brace and strong girder–weak brace member proportions. The influence of using stronger bracing members on the seismic response of frames is also discussed.

● **6.6-85** Vargas N., J., **Analysis of vertical adobe walls** (Analisis de muros verticales de adobe, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 65, 6.

A method for analysis of adobe walls is presented, based on two series of static tests of full-scale models. The first series involving overturning tests showed that fundamental reasons exist for using a design method which is based on mechanical hinges having a high swinging capacity at the time of constant flexion rather than a design method based on the use of traditional plastic hinges. The second series showed that the mechanical hinge method was valid for use in testing walls of different types when the walls were subjected to loads perpendicular to their plane. In conclusion, simplified empirical expressions resulting from the application of the method of virtual work to the mechanisms of collapse are presented; such expressions might prove useful in establishing codes or standards for seismic-resistant design.

● **6.6-86** Minakawa, Y., **The nonlinear equations of motion of shells of revolution: nonlinear vibrations of shells of revolution—part 1** (in Japanese), *Transactions of the Architectural Institute of Japan, 281,* July 1979, 21–30.

Based on the finite deformation theory, the nonlinear equations of motion governing shells of revolution are derived. Because there are some cases where the Donnell equation can not be applied, the finite element method is used. The obtained nonlinear equations of motion have many unknowns, and therefore are not expressed by normal modes. If the modal analysis procedure equivalent to the Galerkin method is applied to the equations of motion they are transformed into equations of motion expressed by normal modes for which the degrees-of-freedom are arbitrarily selected. In the process, it is possible to clarify the coupling mechanism in the nonlinear spring terms caused by the coupling of different harmonic numbers in circumferential directions. Considering this mechanism makes it possible to predict whether there is a nonlinear term in a system, so that the form of the nonlinear equations of motion for the system can be shown.

● **6.6-87** Yamada, M. and Kawamura, H., **Aseismic capacity of steel structures (IV)—low-rise rigid frames with asymmetric braces** (in Japanese), *Transactions of the Architectural Institute of Japan, 283,* Sept. 1979, 58–67.

This paper studies the earthquake-resistant capacity of torsionally rigid and torsionally flexible steel structures with asymmetric braces. Based on the fundament that the steady-state resonance of torsional vibration is an ultimate state, analytical procedures to obtain the resonance-fatigue characteristics of torsional flexible-type steel structures with asymmetric braces are presented. Criteria and procedures for evaluating the earthquake-resistant capacity and safety of such structures are proposed.

● **6.6-88** Seki, M. and Okada, T., **Nonlinear earthquake response of reinforced concrete building frames by computer-actuator on-line system (Part IV: characteristics of earthquake response of reinforced concrete frames)** (in Japanese), *Transactions of the Architectural Institute of Japan, 282,* Aug. 1979, 57–64.

The nonlinear seismic response of reinforced concrete frames is examined. Specific characteristics examined include: (a) the skeleton curve under monotonic loading, (b) the development of cracks, (c) the shear force–displacement relationships during seismic response, (d) the time history of shear force and displacement, (e) the relationships between the maximum displacement response and the lateral strength and/or the initial natural period, and (f) a comparison of analytical and computer-simulated results.

● **6.6-89** Fujimoto, M. and Midorikaw, M., **Inelastic dynamic response of steel space frames (Part 1: single-story, single-bay rigid-jointed space frames composed of columns with H-shaped and box section)** (in Japanese), *Transactions of the Architectural Institute of Japan, 282,* Aug. 1979, 9–21.

In this paper, an analytical method for the inelastic dynamic response of steel space frames is presented. The method assumes that a column segment consists of uniaxially stressed fibers along its length. The responses of single-story, single-bay space frames subjected to the simultaneous action of two horizontal components of sinusoidal ground acceleration are studied using lumped mass, rigid-floor idealization. The center of resistance coincides with the center of mass in the space frames at the initial elastic state. Some of the results are summarized as follows: (1) Torsional deformation of each column with an H-shaped section for which the axial force ratio is less than 0.3 and for which the slenderness ratio is greater than 20 scarcely affects the responses of the space frames. On the other hand, torsional deformation of each column with a box section has a considerable effect on the responses of the space frames, particularly on the torsional response. (2) The responses of the space frames composed of columns with H-shaped sections are greater than the responses of plane frames. However, the responses of the space frames composed of columns with box sections are nearly identical with the responses of plane frames. (3) The torsional responses of the space frames significantly depend on the phase difference between the two components of sinusoidal ground acceleration. The torsional response of the space frames composed of columns with H-shaped sections is

● *See* ***Preface****, page v, for availability of publications marked with dot.*

more influenced by the phase difference than are those frames composed of columns with box sections.

● **6.6-90** Yoshioka, K., Okada, T. and Takeda, T., **Study on improvement of earthquake-resistant behaviours of reinforced concrete column—No. 2: study on failure and ductility of column (Part 2: failure mechanism of columns and strain distribution of reinforcements)** (in Japanese), *Transactions of the Architectural Institute of Japan*, 282, Aug. 1979, 37–45.

Based on experimental data, this study attempts to determine how columns fail and how they retain ductility. Various types of failure, such as failures of plastic hinges at the ends of columns or failures at the centers of columns, were assumed using a truss mechanism which varied with the progress of failure. The mechanism of shear transfer was also studied. Columns which showed large ductilities finally failed at the plastic hinges at the ends of the columns. These columns not only had sufficient shear reinforcement at the hinges, but also sufficient shear strength at the center parts of the columns. In such columns, the web reinforcement strains at the ultimate condition showed large values at the ends of the columns, while the strains became smaller closer to the column centers. When the strains of a portion of the web reinforcements at the plastic hinge region of any of the columns reached yielding strain, the load-carrying capacity of the columns began to decrease until failure. The average value of the maximum strain of web reinforcements in the plastic hinge region of the columns which showed excellent ductility was about 60% of yield strain. The shear force resisted by web reinforcements in the plastic hinge region increased in proportion to the increase of column deflection. Also examined were the transition of strain distribution and the average bond stress distribution of the main bars.

● **6.6-91** O'Rourke, M. J., Singh, S. and Pikul, R., **Seismic behavior of buried pipelines**, *Lifeline Earthquake Engineering–Buried Pipelines, Seismic Risk, and Instrumentation*, 49–61. (For a full bibliographic citation, see Abstract No. 1.2–16.)

The behavior of buried pipelines subjected to seismic wave propagation is investigated in this paper. Simplified procedures for determining upper bounds for the axial strain and curvature in the pipeline as well as relative displacement and rotation at the pipeline joints are discussed. The assumption that the shape of the seismic waves remains unchanged as the waves traverse the pipeline is studied in detail. Finally, methods for estimating the propagation speed of the seismic waves along or with respect to the pipeline are presented.

● **6.6-92** Celebi, M., Chatterjee, M. and Mark, K., **Inelastic seismic analysis of a deeply embedded reinforced concrete reactor building**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(a), Paper K 7/7, 7. (For a full bibliographic citation, see Abstract No. 1.2–20.)

Under high-intensity seismic excitation, a reinforced concrete structure may undergo significant inelastic deformation. This paper studies the inelastic response of a deeply embedded reinforced concrete reactor building for which the behavior is governed by heavy concrete shear walls. Soil-structure interaction is considered in the analysis. The reactor building model is developed for a two-dimensional finite element analysis. An effectively degraded reversed bilinear stress-strain relationship based on currently available experimental information is used for the shear strength of the shear walls. The floor diaphragms are represented as beams and the transverse shear walls are represented as columns. The internals represented by lumped-mass stick models are attached to the reactor building by springs and they share a common base mat with the building.

Two commercially available computer programs are used for the time history inelastic analysis performed for a specified horizontal earthquake of 450 gals at the base of the building. A two-dimensional finite element program is used to study the soil-structure interaction. In this, nonlinearity in both the soil and the structure are considered by an iterative scheme to obtain strain-compatible properties. A second program is used to perform a more realistic nonlinear analysis of only the reactor building and its internals using the multiple input motions along the soil-structure interface determined from the analysis with the first program. Soil-structure interaction effects (translational and rocking) are incorporated in both analyses. Inelastic analytical results are compared with results from an elastic analysis performed for the same specified earthquake. The analysis indicates that rigid body motion for the deeply embedded reactor building dominates the building response. Elastic and inelastic displacements indicate small differences. Shear strains from the finite element solution show that localized post-yield behavior occurs in some of the shear walls.

● **6.6-93** Aziz, T. S., Duff, C. G. and Tang, J. H. K., **Nonlinear transient dynamic response of pressure relief valves for a negative containment system**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 11/5, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

A few nuclear power stations designed and built in Canada (e.g., Pickering Generating Station) utilize a multi-containment arrangement with a common vacuum building to provide a negative pressure containment envelope should a postulated accident occur in one of the containments. In the event that the pressure rises in one of the containments to a certain level, the pressure relief valves which are located in a vacuum duct joining the different containments to the vacuum building will open to relieve the pressure to the vacuum building where a spray system is actuated to condense the incoming steam. These safety-related valves are in Seismic Category B according to Canadian codes and standards; thus, they should remain intact and operational, and cause no loss of containment following a design basis earthquake (DBE). These valves are approximately 6 ft in diameter and consist of a housing in which a piston moves up and down. Two rolling neoprene diaphragms serve to prevent leakage and act as guides to reduce friction around the piston during vertical movements. The large size of these valves precludes any possibility for a full-scale shaking test. In this paper, the basis of the seismic qualification of these valves by means of a nonlinear transient dynamic analysis is presented. The nonlinear analyses conducted take into consideration the true nature of the behavior of the piston during opening and accounts for piston rocking and sway effects, diaphragm folding, and eccentricity of the center of mass and center of rigidity as well as the nonlinearities generated by gaps and friction in the system among others. The nonlinear analysis utilizes an explicit marching scheme to integrate the coupled equations of motion in the time domain. The response of the piston for the postulated simultaneous effect of pressure and an earthquake is obtained for different parameters and accident conditions. Response quantities such as accelerations, displacements, rotations, diaphragm forces as well as opening time during a design basis earthquake are obtained. The results of the different analyses, as related to the functional operability of the valves, are evaluated and discussed.

● **6.6-94** Ishac, M. F. and Heidebrecht, A. C., **Coupled lateral-torsional response of equipment mounted in CANDU nuclear power plants,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/8, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The seismic environment of a piece of equipment located in a nuclear power plant is significantly affected by the analytical model which is used to represent the physical reactor structure. In design, it is common to use a planar lumped mass system as the analytical model. However, real reactor structures are asymmetric and will respond in a combined lateral-torsional manner to a lateral seismic excitation. Consequently, it is important to be able to estimate the significance of this nonplanar response. In this paper, a coupled lateral torsional model is developed as a modification of the uncoupled lateral torsional model by including the torsional degree-of-freedom for each mass point and taking into consideration the effect of eccentricities between the centers of mass and rigidity at each floor level. The lateral and rotational time-histories at each floor level are characterized by lateral and rotational floor response spectra at the mass centroid. These time histories are also combined to determine the lateral floor response spectra at the extreme edges of each floor mass. A typical CANDU reactor building is subjected to the E-W component of the 1940 El Centro, California, earthquake, and analyzed as indicated above. The results show that the effect of torsion may cause some variations in the floor response spectra, resulting both from the change in coupled dynamic properties and from the contribution of rotational motion to the lateral response at the edges of any particular floor level.

● **6.6-95** Subudhi, M. et al., **A three-dimensional computer code for the nonlinear dynamic response of an HTGR core,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A three-dimensional dynamic code has been developed to determine the nonlinear response of an HTGR core. The HTGR core consists of several thousands of hexagonal core blocks. These are arranged in layers stacked together. Each layer contains many core blocks surrounded on their outer periphery by reflector blocks. The entire assembly is contained within a prestressed concrete reactor vessel. Gaps exist between adjacent blocks in any horizontal plane. Each core block in a given layer is connected to the blocks directly above and below it by three dowell pins. The present analytical study investigates the nonlinear response of the reactor core blocks in the event of a seismic occurrence. The computer code is developed for a specific mathematical model which represents a vertical arrangement of layers of blocks. This comprises a "block module" of core elements which would be obtained by cutting a cylindrical portion consisting of seven fuel blocks per layer. It is anticipated that a number of such modules properly arranged could represent the entire core. Hence, the predicted response of this module would exhibit the response characteristics of the core.

The basic block element employed is a finite discrete mass having five degrees-of-freedom, rotations about the vertical axis being excluded. The governing equations for each mass contain terms from the inertia effect, the restoring forces, and the surrounding wall input forces. This program sets up five second-order ordinary differential equations for each mass, which are further broken into ten first-order ODE's. GEAR, a multistep integration package for stiff ODE is used for solving these equations. A basic force algorithm is written for vertical forces and for horizontal plane forces for a typical layer of blocks. Each layer of seven hexagonal blocks is arranged with one in the center surrounded by the remaining six. The entire module is contained in an 18-faced constraint wall. The wall can move with any assigned input time history. In any horizontal layer, there are sixty separate surfaces for any potential

● *See **Preface**, page v, for availability of publications marked with dot.*

contact between any two adjacent surfaces. When such contact occurs, the blocks involved experience a compressive force between them. Since this force is equal and opposite in nature, it need not be calculated twice for individual surface points of contact whenever two adjacent blocks are involved. Each block face contact is simulated by two gapped-restoring elements attached at the top and bottom ends of the block. These restoring elements are arranged among the seven blocks in such a way that for any layer there exist thirty independent interelement forces to be calculated at each end of the block. In case of vertical forces, each block is attached with six vertical restoring elements at the six corner points. It should be noted that each restoring element has gap elements in the springs and exhibits only compressive action.

The results obtained were compared with those derived from an existing two-dimensional code (OSCVERT). In one plane of symmetry, there are three masses for which the simulated motions are close to the two-dimensional results. However, a coupling from the third direction has been indicated from the three-dimensional results.

● **6.6-96** Curreri, J. et al., **Response of a nonlinear system to various spectral excitation time decompositions,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 8/3, 6. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper discusses the effects of different acceptable time histories that have been applied to a linear system and a nonlinear system. The time histories have been obtained from a spectral description of an earthquake event. The nonlinear system is taken to be a linear one to which a cubic hardening term has been added. The SIMEAR code has been modified to decompose a given spectra to the time domain. By successive iterations, acceptable time functions are generated. The paper reports on the maximum response variations that are obtained for excitation of a linear and a nonlinear degree-of-freedom system. It is shown that, for some system characteristics and time decompositions, the linear response is greater than the nonlinear response. In these cases, the linear natural frequency is favorably located in the excitation spectrum. As the natural frequency is shifted with respect to the excitation spectrum, the relative magnitudes of linear and nonlinear response change. Under some conditions, the nonlinear response becomes considerably larger than the linear response. It appears that this type of response characteristic is possible only for a nonlinear system with a jump phenomena, like an HTGR. The cubic-hardening system that is investigated in the paper is similar to a bilinear one; both have multiroot possibilities and jump phenomena. The same type of critical composition of the exciting time function may also affect the bilinear system response. For these cases, certain qualifications would have to be imposed on the conditions under which the linear solution is used as a conservative case for the maximum response.

● **6.6-97** Nelson, T. A., **Reserve seismic capacity determination of a nuclear power plant braced frame with piping,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 3/10, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes a project sponsored by the U.S. Nuclear Regulatory Commission to investigate the inelastic behavior of a representative noncategory I structure to determine the amount of reserve seismic capacity that is available beyond elastic design levels. This reserve capacity can be an important consideration when evaluating the ability of existing structures to withstand seismic hazards for which regulations have been upgraded. A typical diagonally braced steel frame was developed to determine the amount of reserve capacity available beyond the elastic design levels. The frame was analyzed first using elastic static and dynamic analyses. The loadings included dead and live load, an equivalent static lateral earthquake load, two response spectra, and a suite of eight earthquake time history records. The response spectra used were those of Housner and Regulatory Guide 1.60. The time histories represented different site conditions, distances to causative faults, and magnitudes. The lateral static load and Housner spectrum represent vintage design criteria, while the R.G. 1.60 and time history analyses reflect current methodology. The elastic limit responses of the structure were determined along with the accompanying threshold peak ground accelerations (threshold g values). The frame was then analyzed using the program DRAIN-2D to perform two-dimensional elastic-plastic analyses for the eight time histories. The peak ground accelerations were scaled upward in succeeding analyses until the resulting frame deflection became excessive. The peak accelerations corresponding to this deflection of the frame were called the ultimate g values. By comparing the threshold g values with the ultimate g values, the reserve capacity of the structure was determined. The analysis of the frame represents only one aspect of the problem. To remain functional, the piping and equipment contained within the structure must be operable during and after a seismic event. Therefore, a representative piping system was developed which consisted of vertical and horizontal runs of 8- and 10-in. piping, a pump, valves, elbows, tees, and a reducer. A model incorporating the frame and piping system was subjected to the eight time histories and two spectra using elastic analyses. The threshold g values for operation of each component were calculated based on the limits specified by manufacturers or on the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

● *See **Preface**, page v, for availability of publications marked with dot.*

The results of the study show that the braced frame alone had a reserve capacity of more than five times greater than the design level. The design level response was controlled by buckling of the bracing, and the ultimate level response was controlled by a one-foot deflection limitation. Both limiting criteria were based on the mean response to the eight time histories. The analysis of the combined frame and piping indicated that the pump was the controlling element of the frame and pipe system, reducing the total available reserve capacity to 2.6 times the design level.

● 6.6-98 Wolf, J. P. and Skrikerud, P. E., **Mutual pounding of adjacent structures during earthquakes**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 8/9, 12. (For a full bibliographic citation, see Abstract No. 1.2-20.)

For adjacent structures separated by a small gap, there is a danger of their colliding in the event of a sufficiently large earthquake excitation. This mutual-pounding phenomenon has often caused extensive structural damage in past earthquakes. When retrofitting nuclear power plants for increased seismic requirements, the size of the existing gap may be found to be too small. This can also arise when existing structures are recalculated with modern analytical procedures which take into account such parameters as soil-structure interaction, including the material nonlinearities of the soil and the superstructure. The consequences of the potential pounding have to be determined in order to be able to decide if the given structural configuration has to be altered. To examine the global response, the pounding structures are represented as simple spring-mass systems. Introducing an impact spring, which only acts in compression, leads to a nonlinear dynamic system. Parametric studies are performed. The response for transient as well as for steady-state vibrations is compared to the corresponding linear results. When the consequences of pounding are found to be unacceptable, the structural system has to be modified to reduce the response. Of the various ways for achieving this, the solution consisting of a spring-dashpot system between the two structures is examined parametrically.

By way of illustration, the response of a typical reactor building which is subjected to the pounding of an adjacent frame structure during an earthquake is determined. Relative displacements, stress resultants, and in-structure response spectra are compared to those of the linear case where the gap is sufficiently large. The comparison is also extended to the results obtained from aircraft impact. For the harmonic excitation, the well-known multiple solutions are observed when sweeping the frequency for constant amplitude as well as when increasing and decreasing the amplitude at a certain frequency. For real structures subjected to earthquake excitation, the influence of pounding has a minor effect on the overall response away from the zone of impact. However, in-structure response spectra are increased in the high-frequency range. Tuning reduces this magnification drastically. Nuclear structures can withstand a substantial amount of pounding, especially if they have been designed for the loading case of aircraft impact.

● 6.6-99 Cofer, L. J. et al., **The influence of uplift and sliding nonlinearities on seismic response of a small test reactor building**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(a), Paper K 6/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents the results of an investigation performed to determine the influence of uplift and sliding nonlinearities on the seismic response of a small test reactor building, which consists of a 61-ft-high concrete structure, with a 20-ft embedment, supported on a 70-ft diameter circular foundation slab. Parametric analyses were first performed using a linear elastic lumped-mass model. The soil shear modulus, area of contact between the base slab and the soil, depth of embedment, and modal damping were varied to investigate their influence on the response of the structure. A realistic case for the linear elastic analysis was established for comparison against nonlinear analyses.

Nonlinear analyses were performed using two different lumped-mass models. In the nonlinear model A, the uplift and sliding nonlinearities were modeled by rotational (rocking) and translational springs, respectively. A nonlinear moment-rotation relationship was developed for the foundation and was incorporated in the rotational (rocking) spring. A nonlinear force-displacement relationship for sliding was also developed and was incorporated in the translational spring. Time history dynamic analyses were performed considering each nonlinearity separately. Maxima of displacements, accelerations, forces, and selected floor spectra were computed. The nonlinear model B employed a set of distributed nonlinear soil springs to model the uplift effects. The springs were not allowed to carry any forces under tension. The building was modeled by two lumped-mass cantilevers connected by nonlinear slab elements which were allowed to crack and yield. Time history dynamic analyses were performed and maxima of response quantities were computed.

The results on nonlinear analyses using models A and B were compared with the corresponding results from the linear elastic analyses and the influence of uplift and sliding nonlinearities on the structural response was evaluated. It was found that the maximum story shears and overturning moments were reduced as much as 50 percent as a result of the combined effect of uplift and sliding nonlinearities. It was also found that the maximum spectral accelerations were reduced by as much as 20 percent as a result of the

● *See **Preface**, page v, for availability of publications marked with dot.*

uplift effect only. The paper concludes with a discussion of results and recommendations for future investigations.

● **6.6-100** Koplik, B., Subudhi, M. and Curreri, J., **Nonlinear response to the multiple sine wave excitation of a softening-hardening system,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 10/7, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In studying the earthquake response of a HTGR core, it was observed that the system can display softening-hardening characteristics. This is a great consequence in evaluating the structural safety aspects of the core. In order to obtain a better understanding of the governing parameters, an investigation was undertaken with a single degree-of-freedom system having a softening-hardening spring characteristic and excited by multiple sine waves. A cubic nonlinearity in stiffness is introduced, and the governing differential equation is given. This type of system has as many as five roots at a given excitation amplitude and frequency. A parametric study varying the input amplitudes and the spring characteristics is performed. Transients are introduced into the system, and the jump phenomena between the lower softening characteristics to the higher hardening curve are studied. Numerical results are obtained for the case of two sine wave inputs of different amplitudes applied to a softening spring. In order to generate the resulting curves, it is necessary to sweep down in frequency. By choosing four different combinations of sinusoidal inputs, results are plotted for amplitude vs. frequency. These curves clearly demonstrate the existence of a sizable subharmonic contribution. Examination of several combinations of sine excitations makes it possible to establish large discontinuities in the response. In particular, a large discontinuity is noted in the vicinity of 25 cycles/sec. For this case, the jump in response increased by a factor of 3.5. This kind of discontinuity was shown to exist in the case of the hardening spring as well as the softening spring, which is of significance because the restoring force curve for the HTGR is actually softening-hardening.

Further investigation into the dynamics of a single degree-of-freedom system with a cubic nonlinearity was carried out by introducing an exponential decaying term in each of the components of the sinusoidal forcing function. This study was undertaken because of the significant effect that earthquake duration is known to have on the dynamic response of a structure.

● **6.6-101** Thakkar, S. K., **Numerical methods for nonlinear dynamic structural analysis,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-25-30.

The purpose of this paper is to present different techniques that are available for nonlinear dynamic analysis and to present methods of numerical integration. The guidelines for and limitations of using explicit and implicit time integration are discussed from the point of view of computational efficiency and types of nonlinear problems. The advantage and disadvantage of using higher order time integration schemes are also discussed. A survey of computer programs available for nonlinear dynamic analysis is presented and their salient features are identified.

● **6.6-102** Jain, A. K., **Efficient numerical models for nonlinear analysis of braced frames,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-19-24.

Two numerical models are presented for analysis of the nonlinear dynamic behavior of steel column and bracing members. The buckling model is a multilinear model which accounts for reduction in compressive strength in the first two cycles and an increase in member length. The end moment-buckling model also accounts in a simple and realistic manner for interaction between the axial and flexural inelasticities in steel members. These models have been developed for use with a general purpose computer program. The salient features of the element subroutines are discussed.

● **6.6-103** Buchholdt, H. A., **Non-linear dynamic response analysis by minimization of the total potential dynamic work,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-43-49.

This paper proposes a method for calculating the nonlinear dynamic response of tensioned structures. The method is based upon minimization of the total dynamic energy potential using the methods of Newton-Raphson and conjugate gradients.

● **6.6-104** Radhakrishnan, R., Santhakumar, A. R. and Swamidurai, S., **Non-linear finite element analysis of prefabricated shear walls,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-1-5.

A method presented in the paper is used to predict the history of stresses, deflections, and crack propagation of panel-walled structures with reinforced and unreinforced joints. The discrete finite element method that has been adopted uses quadrilateral elements with isoparameteric formulation. The model recognizes the elastoplastic behavior of the joint, the presence of reinforcement across the joint, and the loss of stiffness caused by cracking. The application of the analysis to a 20-story shear wall structure is presented and compared with Lewicki's linear solution.

● **6.6-105** Santha Kumar, A. R., **Nonlinear finite element analysis of reinforced concrete coupled shear walls,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-31-36.

The paper describes the details of an incremental iterative nonlinear finite element analysis used to assess the behavior of reinforced concrete structures. The analysis predicts stresses, deflections, crack propagation, crushing of concrete, yielding of steel, and ultimate loads. For the example given, the predicted results are compared with: (a) those results obtained by an independent, nonlinear, elasto-plastic finite difference analysis and (b) those results observed during testing of a quarter-scale reinforced concrete coupled shear wall model. The results correlate well. The paper shows that the program developed is capable of simulating crack propagation in reinforced concrete structures. The results show the necessity of considering the strain-hardening effect while modeling certain types of steel finite elements.

● **6.6-106** Sharma, S. S., Jain, P. C. and Trikha, D. N., **Computer aided inelastic analysis of R. C. frames,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-19-24.

A method is presented to predict the response history of reinforced concrete frames under monotonically increasing loads. Both material and geometrical nonlinearities are included in the analytical model. A computer program for the proposed analysis is described. A beam is analyzed using the method and conclusions are drawn.

● **6.6-107** Chakrabarti, S. C. and Nayak, G. C., **Effect of shear deformability of vertical joints on the structural response of prefabricated shear wall system,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-69-75.

A multipanel prefabricated shear wall system coupled at the vertical joints by shearing media has been analyzed by means of the shear continuum technique. A computer program has been developed to study the effect of shear deformability of the vertical joints on the overall structural response of the system under lateral load. The relative importance, with respect to overall height and width, of the shear wall and the effect of vertical joints on the wall have been studied. The solution determined by means of the shear continuum technique has been verified by comparison with a finite element solution of a partially bonded two-layered beam system with a slip surface at the vertical joint.

● **6.6-108** Kawakatsu, T. et al., **Floor response spectra considering elasto-plastic behaviour of nuclear power facilities,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 9/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper evaluates the results of an elastoplastic dynamic analysis of an auxiliary building for a PWR power plant. The nonlinear response of the structure is affected by the hysteresis curves of the structural members. In this paper, three hysteresis curves (origin-oriented-type, degrading trilinear-type, and slip-type) are applied to the time-history response analysis of the auxiliary building. The geometrical nonlinearity of the soil rocking spring caused by the separation of the foundation from the soil surface is also considered. Also discussed in the paper are the floor response spectra obtained from elastic and elasto-plastic systems. The spectra are calculated from the time-history acceleration of the auxiliary building at selected floor levels using a single degree-of-freedom mass-spring-dashpot system with a specific damping ratio.

The three major parameters for this study are hysteresis curves, ground motions, and input motion levels. The hysteresis curves are based on shear force-deformation characteristics of reinforced concrete walls. The ground movements produced by two simulated earthquakes provided the design ground response data. The input acceleration range was 300-1000 gal. The results of responses to severe earthquakes can be summarized as follows: (1) the model structure exhibited partially nonlinear response, (2) response forces did not increase in proportion to the magnitude of the input motions (3) the peak level and the shape of the floor response spectra were affected by the characteristics of the hysteresis curve.

● **6.6-109** Powell, G. H., de Villiers, I. P. and Litton, R. W., **Implementation of endochronic theory for concrete with extension to include cracking,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 2/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The aim of the research described in this paper has been to contribute to the development of a general nonlinear analysis procedure which can account for all important mechanical properties of concrete and which is applicable to a wide variety of structures and loadings. The paper is based in part on research by Litton, who developed a general theory for a material which is elastic in compression and cracks in tension, and in part on the research of deVilliers, who extended the procedure to include inelastic behavior in compression. In this latter work, Bazant's

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

"endochronic" theory for concrete, which describes the inelastic behavior of concrete in compression and in tension up to cracking, was judged to be the most comprehensive theory available. The theory is particularly valuable in that it accounts for dilation of the concrete as it crushes, so that the beneficial effects of confinement can be modeled. Bazant's theory was adopted and extended to include the effects of cracking, including the effects of "tensile softening" and cyclic opening-closing-reopening of cracks. The cracking theory is general and elegant and can be applied to both two- and three-dimensional problems. The theoretical formulation is similar to that for plasticity in metals.

A two-dimensional finite element has been developed for the analysis of plane and axisymmetric concrete structures. This element has been incorporated into ANSR, a general purpose computer program for the static and dynamic analysis of nonlinear structures. The procedure can be extended to three-dimensional solids without major difficulty. The model as currently implemented does not account for shear slip across cracks, which for some problems can be a serious omission. Also, shrinkage and creep are currently ignored. The theoretical formulation centers primarily on determination of the tangent stress-strain relationship for the cracked inelastic material. The most complex aspect of the computational procedure is the "state determination" calculation, in which a new stress state is determined given an existing state and a strain increment.

The agreement with experimental results is far from exact but encouragingly close. Computational difficulties were experienced with slow convergence during cracking, and numerical instability when the concrete became severely cracked under cyclic loads. A viscoplastic type of procedure, involving the addition of viscous damping, was successful in eliminating these numerical instability effects.

● **6.6-110** Muto, K. et al., **Nonlinear analysis of a BWR reactor building subjected to both thermal and earthquake loadings,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 8/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

It is well known that, when a reinforced concrete member is subjected to thermal loads, cracking occurs which decreases overall member stresses. However, the influence of thermal cracks on the earthquake response of a structure has not yet been discussed. The objective of this paper is to clarify both the thermal and dynamic nonlinear behavior of a BWR MARK II-type reactor building which is composed of thick walls such as a shield wall and inner and outer structural walls.

In order to investigate crack patterns and member stresses of the reactor building under normal operating conditions, elastic and elasto-plastic analyses are carried out using the finite element method, wherein two cases of reinforcement for the shield wall, 0.90 and 0.45 percent, are adopted. In the elastoplastic analysis, a compressive concrete element and a reinforcing bar element are both assumed to be linear, while a tensile concrete element is assumed to loose its stress when the principal stress reaches 20 kg/cm^2. The results are as follows: (1) Cracking takes place over the areas from the middle to the upper conical part of the shield wall even in normal operating conditions when the difference in temperatures between the inner and outer surface is specified to be 40°C. (2) Compressive stresses of concrete at the corresponding portions are very similar in the elastic and the elastoplastic analyses. Furthermore, the amount of reinforcing bars does not influence the compressive stresses of concrete. (3) Bending moments determined in the elastoplastic analysis are remarkably smaller than those determined in the elastic analysis. For example, the longitudinal bending moments at the upper conical part of the shield wall are reduced to about 70 percent of those determined by the elastic analysis, and the circumferential bending moments at the same location are reduced to about 80%.

An earthquake response analysis, in which the vibration model is a lumped mass and spring system, is performed. Restoring force characteristics for springs are idealized after defining several values for diagonal shear cracking of concrete and yielding of reinforcing bars. The effects of thermal cracks anticipated above are introduced in calculating initial rigidities. From the dynamic responses against severe earthquakes, the following results are obtained by comparison with the results of the elastic analysis: (1) Significant differences are recognized between the elastic and the elastoplastic analyses. For example, the shears and moments of the shield wall in the latter case are smaller than those in the former. (2) Maximum story drifts obtained by the elastoplastic analyses are at most 1.8 and 5.0 times the elastic limit during 0.3 g and 0.45 g maximum acceleration earthquakes respectively, which suggests that the large extent of energy absorption can be expected as a result of nonlinear deformation capacities. (3) Although the shield wall suffered because of the thermal loads, the earthquake responses of the overall reactor building are found to be scarcely affected by the existing cracks.

● **6.6-111** Dubois, J., Bianchini, J. C. and de Rouvray, A., **Coupled damage modes (CDM) plasticity models for the simulation of complex materials used in reactors,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 2/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

● *See **Preface**, page v, for availability of publications marked with dot.*

Some materials which are used in nuclear power reactors or for their confinement, such as concrete, graphite, shock absorbing materials, rocks, etc., often possess a complex constitutive behavior that can be characterized by a certain number of damage modes (e.g., cracking, shearing, compaction), which can occur concurrently. The CDM family of constitutive models presented in this paper is a systematic and efficient procedure for assembling a plasticity model that can represent the main features of the material described by means of individual damage modes, damage parameters (representing the amount of damage in a particular mode), and by a consistent coupling between the damage modes. The CDM models use the classical incremental theory of plasticity with the following modifications: several yield functions can be used simultaneously; Koiter's generalization is used to activate several damage modes simultaneously; and damage differential equations are elaborated with damage functions in order to describe the evolution of each damage parameter.

Two examples of application of the models are given. In order to evaluate the behavior of a large underground opening for a nuclear power plant, a specialized constitutive model (UJPLAS) has been developed for the rock mass. A post-rupture model (POSTRU) is used to simulate the behavior of concrete. The inelastic modes used in the model correspond to tensile cracking, shear flow, and hydrostatic compaction. The examples show that, for a wide range of materials, adapted CDM constitutive models can be generated by a systematic and efficient method which takes into account standard laboratory results and individually characterizes the inelastic damage modes of the materials.

● **6.6-112** Morel, A. et al., **Study of an axisymmetric model for the parametric analysis of a 3D complex steel structure,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 3/7, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A design analysis of a slab (a metallic annular plate filled with concrete) of a Super-Phenix fast reactor power station showed that the slab exhibited a simple state of deformation even though the structure and the state of stress were complex. For comparison, a parametric analysis was conducted of an axisymmetric model of the slab. Described in this paper are a three-dimensional nonlinear analysis of a portion of the slab under several loads, the determination of the parameters describing the linear and nonlinear behavior of the axisymmetric model under static and dynamic loads, and a comparison of the behavior of both models.

● **6.6-113** Mittal, A. K., **Lower bound on forcing amplitude for stability of forced oscillations in a third order non-linear system,** *Journal of Sound and Vibration,* **67,** *1,* Nov. 8, 1979, 69-74.

An example of a third order nonlinear system is given which exhibits the property that stable symmetric forced oscillations exist only if the forcing amplitude is greater than a critical value.

● **6.6-114** Taniguchi, H. and Takanashi, K., **Earthquake response analysis of frames with bolted connections** (in Japanese), *Seisan-Kenkyu,* **31,** *11,* 1979, 30-33.

● **6.6-115** Vito, R. P. and Cabak, G., **The effects of internal resonance on impulsively forced non-linear systems with two degrees of freedom,** *International Journal of Non-Linear Mechanics,* **14,** *2,* 1979, 93-99.

The method of multiple time scales is used to study the nonlinear oscillations of impulsively forced systems under conditions of internal resonance. A partial analytical solution is obtained. The method is illustrated by an example in which the internal resonance effects are shown to be significant.

● **6.6-116** Shieh, R. C., **Slope-deflection method for elastic-viscoplastic frames,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM6,* Proc. Paper 15052, Dec. 1979, 953-969.

The conventional slope-deflection method of beam and frame analyses is extended to the case of structural materials that follow an elastic-linear strain-hardening, viscoplastic constitutive power law. Slope-deflection equations are derived in an incremental form for the cases of linear power law with strain-hardening and nonlinear power law without strain-hardening under the assumption that the effect of axial force/bending moment interaction on inelastic deformation is negligibly small. These equations are subsequently used in developing a computerized large displacement/lumped mass frame analysis procedure. Two approximate techniques applicable to shear frame analysis are developed for the general constitutive power law case. Three example problems are presented for mild steel cantilever beams and shear frames subjected to strong blast, impact, and earthquake loadings. The importance of the inclusion of material strain rate effects in the inelastic analysis of such dynamic problems or similar problems is emphasized.

● **6.6-117** Kan, C. L. and Chopra, A. K., **Linear and nonlinear earthquake responses of simple torsionally coupled systems,** *UCB/EERC-79/03,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 120. (NTIS Accession No. PB 298 262)

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

The effects of torsional coupling on the earthquake response of simple single-story structures in both the elastic and inelastic ranges of behavior are analyzed. The structures considered are symmetrical about one principal axis of resistance, resulting in coupling only between lateral displacement along the perpendicular principal axis and the torsional displacement. Torsional coupling arising only from eccentricity between centers of mass and elastic resistance is considered. Systems with several resisting elements, columns, and walls are idealized by a single-element model. Responses of such a model to a selected earthquake ground motion are presented for a wide range of the basic structural parameters. The results presented include maximum lateral and torsional deformations of the system as well as maximum deformations of individual columns. It is shown that the inelastic response is affected by torsional coupling to generally a lesser degree than elastic response. Procedures are presented for estimating, to a useful degree of approximation, the maximum responses of elastic and inelastic systems from the corresponding response spectra and the maximum deformations of individual columns from the displacements at the center of mass.

● **6.6-118** Viwathanatepa, S., Popov, E. P. and Bertero, V. V., **Seismic behavior of reinforced concrete interior beam-column subassemblages,** *UCB/EERC-79/14,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 198. (NTIS Accession No. PB 301 326)

This report details experiments conducted on beam-column subassemblages to determine their seismic behavior and evaluates the significance of the analytical and experimental results obtained. Two virgin concrete subassemblages and one repaired subassemblage were tested. A horizontal force was applied to one subassemblage to generate a large single hysteresis loop, the initial part of which provided information on monotonic loading. Once the loading sequence was completed, the specimen was repaired by epoxy injection processes and an incremental cyclic load was applied until failure occurred. The second specimen was tested to failure by applying a loading sequence similar to the sequence applied to the repaired subassemblage.

● **6.6-119** Fujiwara, T., **Earthquake response of framed structures having aseismic elements–Part II,** *Transactions of the Architectural Institute of Japan, 286,* Dec. 1979, 65–73.

This paper describes the elastic and elastoplastic dynamic responses of braced frame structures with elastoplastic joints at the end of the frame members and at the center of the braces. The responses are obtained using a method of dynamic analysis presented in the first part of the author's paper.

● **6.6-120** Vallenas, J. M., Bertero, V. V. and Popov, E. P., **Hysteretic behavior of reinforced concrete structural walls,** *UCB/EERC-79/20,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 266. (NTIS Accession No. PB 80 165 905)

Experimental and analytical responses are studied for reinforced concrete structural walls subjected to high shear earthquake loading conditions. Results are presented of eight earthquake simulation tests on 1/3-scale structural R/C wall subassemblage model specimens. The prototypes were ten- and seven-story buildings designed to current code provisions. Details of the test setup, the models tested, and test procedure are summarized. The main experimental results are evaluated in terms of the hysteretic characteristics (strength, deformation, and energy dissipation capacity), the modes of failure, ease of construction, and effectiveness of repair. The parameters studied were type of confinement in the boundary elements (hoop vs. spiral); wall cross section (rectangular vs. framed where the boundary elements protrude from the surface of the wall); moment-to-shear ratios; monotonic and cyclic load programs; and repair procedures. Excellent behavior was obtained in well-designed R/C structural walls. Slender walls with rectangular cross sections were found to have problems with out-of-plane stability.

The analytical work included modeling of the wall behavior under monotonic loading and high shear conditions. The models developed included a breakdown of the overall deformation into three components, flexural, shear, and fixed-end deformations. The possibility of extending these models to the case of cyclic loading is investigated. Present code design methods for walls are assessed, the seismic-resistant design implications of the results are discussed, and areas of further study are recommended.

● **6.6-121** Forzani, B., Popov, E. P. and Bertero, V. V., **Hysteretic behavior of lightweight reinforced concrete beam-column subassemblages,** *UCB/EERC-79/01,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 116. (NTIS Accession No. PB 298 267)

This paper describes an experimental investigation into the behavior of interior beam-column joints of a ductile moment-resisting frame constructed of lightweight aggregate concrete. Emphasis is placed on the effects of bond deterioration in the joint region. Results of experiments carried out on two lightweight R/C specimens are compared with similar experiments on specimens constructed of normal weight concrete. Comparison reveals a similar performance when the specimens are subjected to monotonically increasing lateral loads, but a considerably poorer performance of the lightweight specimens when subjected to cyclic loading similar to that which can be expected from severe seismic excitation. Recommendations are given for improving observed behavior and for further research.

● 6.6-122 Wolde-Tinsae, A. M., Tso, W. K. and Heidebrecht, A. C., **Externally reinforced concrete block walls,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 474-484. (For a full bibliographic citation, see Abstract No. 1.2-21.)

The in-plane cyclic behavior and out-of-plane strength of unconfined externally reinforced walls are investigated. Experimental results are presented for an unreinforced wall and two externally reinforced walls of similar construction but with different bearing loads. The walls are evaluated on the basis of ductility, stiffness degradation, and energy absorption and dissipation. Damage patterns and effects of bearing loads are discussed. The externally reinforced walls showed a ductile-type behavior with an increase in bearing stress resulting in a decrease in stiffness degradation. The externally reinforced walls displayed an improvement of about 1200 percent in out-of-plane strength over the unreinforced wall.

● 6.6-123 Chin, M. W. and Bailey, K. A., **Earthquake analysis of multi-storey car parking structures,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 365-383. (For a full bibliographic citation, see Abstract No. 1.2-21.)

Typical auto parking structures possess unusual framing systems which introduce structural discontinuities both in geometry and stiffness distribution. Additionally, these types of structures frequently exhibit cracking at the beam/column connections. These cracks appear even before the forms are removed. To date, the exact cause of this phenomenon is not known. Such features necessarily cause these structures to have uncertain dynamic properties. In this paper, a detailed study is made of the implications of the equivalent static and dynamic analyses as recommended in current seismic codes for such structures. Particular reference is made to the 1975 National Building Code of Canada and the 1975 Structural Engineers' Assn. of California provisions. The results obtained from the recommended methods are compared with those obtained from an approximate reserve energy analysis method, which takes inelastic behavior into account. The elastic response of the structure to a simulated El Centro acceleration record is also examined. It is shown that substantial differences in the level of lateral forces are obtained from the different approaches and it is concluded that, for the type of structure analyzed, the response spectrum technique provides a fairly rapid method of analysis which could easily be used while the reserve energy method gives a good indication of what the actual behavior of such structures is likely to be in a severe earthquake.

● 6.6-124 Spencer, P. N., ed., **The design of steel energy absorbing restrainers and their incorporation into nuclear power plants for enhanced safety,** *UCB/EERC-79/07-79/10,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1979, 4 vols.

The long-range objectives of this project are to significantly enhance safety and reduce operational costs for nuclear power plants. This would be done through utilizing, in piping system restrainer devices, the very large energy-absorbing capabilities of certain steels undergoing plastic deformation. Specifically, the objectives are (1) to develop an analytic program confirming the viability of elastic-inelastic deformation of restrainer devices as a means of controlling piping responses during seismic events and during extreme loadings caused by operational events such as water hammer, pipe whip, etc.; (2) to develop solid-state, energy-absorbing restrainers capable of meeting the criteria of the analytic program, and to confirm their behavior through experimental testing programs including shaking table tests; and (3) to convert (1) and (2) into a code position acceptable to the appropriate ASME committees and the U.S. Nuclear Regulatory Commission. The short-range objectives are (1) to demonstrate the technical and economic feasibility of an extended R&D program to accomplish the long-range objectives; and (2) to produce a plan acceptable to the nuclear power industry and the U.S. Nuclear Regulatory Commission for undertaking such a program.

The titles of the four volumes follow: Volume 1—Summary Report; Volume 2—The Development of Analyses for Reactor System Piping; Volume 3—Evaluation of Commercial Steels; and Volume 4—Review of Current Uses of Energy Absorbing Devices.

6.6-125 Bakhtin, B. M. and Dumenko, V. I., **Investigation of the earthquake resistance of a concrete gravity dam** (Issledovanie seismostoikosti betonnoi gravitatsionnoi plotiny oblegchennogo profilya, in Russian), *Gidrotekhnicheskoe stroitel'stvo, 5,* May 1979, 17-20.

A newly developed model test material is described, along with a procedure for testing the material and its salient physico-mechanical characteristics. Low-modulus model material of this type is useful in successfully resolving problems of the nonlinear response of structures loaded dynamically and statically, when small test models are employed. Test results are cited for lightweight models of the Kuprsai Dam. The model earthquake response shows the top quarter of the dam to be the most seismically hazardous part. Recommendations are offered for ways to strengthen the design to increase the safety factor. Changes in the amplitude-frequency characteristics of the dam in response to intense seismic effects are described.

● See ***Preface,*** *page v, for availability of publications marked with dot.*

6.6-126 Kilimnik, L. Sh., **Damage to structures in strong-motion earthquakes** (Povrezhdeniya konstruktsii pri sil'nykh zemletryaseniyakh, in Russian), *Beton i zhelezobeton, 6,* June 1979, 11-13.

Emphasis is placed on factors determining the degree of damage to reinforced concrete structures in earthquakes. Diagrams are presented of typical damage and failure occurring as a result of the stress-strain state of the structural members and the structure as a whole. Attention is given to the practical feasibility of calculating the ability of structures to deform elastoplastically when subjected to intense seismic excitation.

6.6-127 Rzhevskii, V. A. and Avanesov, G. A., **Limit state parameters of reinforced concrete members and frames** (Parametry predel'nykh sostoyanii zhelezobetonnykh elementov i ramnykh karkasov, in Russian), *Beton i zhelezobeton, 6,* June 1979, 17-18.

A study of the elastoplastic response of reinforced concrete members and frame systems to dynamic and static alternating loads is discussed. Emphasis is placed on the response of structures in the inelastic range as a factor to aid in the ability of structures to withstand strong earthquakes. Reinforced concrete model structures were loaded in flexure, and H-columns were subjected to compressive loading. Limit state behavior was examined as a function of reinforcement ratio, transverse reinforcement, and stiffness. It was found that symmetric reinforcements greatly improve plastic behavior, and it is recommended that transverse reinforcements be increased in the area of plastic hinges.

● **6.6-128** Litton, R. W. and Gidwani, J. M., **Failure criteria of reinforced concrete structures,** *AFWL-TR-77-239,* U.S. Air Force Weapons Lab., Kirkland Air Force Base, New Mexico, May 1979, 2 vols., 380.

Volume I of this final report is entitled "Literature Survey & Proposed Analytical Models" and Volume II is entitled "Analytical Model and Response Data." In Volume I, the literature survey reviews experimental and analytical studies relevant to the theoretical investigation of failure criteria for reinforced concrete structures. An extensive list of relevant references used in the survey is also presented. In Volume II, failure criteria defining the complete loss of section strength for reinforced concrete sections are defined. Failure envelopes obtained from a three- dimensional finite element analysis with a three-dimensional nonlinear constitutive material model are presented in terms of deformations for various rectangular and cylindrical sections. Applications and examples of the use of these failure envelopes are also presented.

6.6-129 Ugai, K., **Dynamic analysis of underground pipelines under the condition of axial sliding,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 29-30. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 272,* Apr. 1978, 27-37.)

In this study, the definition is used that sliding of buried pipes in the axial direction occurs when axial shear stress acting upon the outer surface of pipes surpasses the frictional force between the pipes and the soil. The dynamic response characteristics of buried pipes of infinite length are investigated by means of the vibrational theory of beams on elastic or elastoplastic foundations under the condition of axial sliding or no sliding. The hysteresis curve relating the axial shear stress and the relative displacement between the pipes and soil is considered to be completely plastic, elastoplastic, or bilinear. Incident waves are considered to be plane, compressional, and harmonically time varying. The dynamic coefficient of the axial subgrade reaction for infinitely buried pipes is considered, and the inertia force of pipes is neglected. The dynamic behavior of curved pipes and pipes of finite length is examined under axially sliding conditions. Based on the results of these investigations, the current design standards and conventions are examined and some unresolved problems are indicated.

● **6.6-130** Fagundo, Jr., F. E., Gergely, P. and White, R. N., **The behavior of lapped splices in reinforced concrete beams subjected to repeated loads,** *79-7,* Dept. of Structural Engineering, Cornell Univ., Ithaca, New York, Dec. 1979, 288.

This report summarizes the results of the first phase of an investigation of lapped splices in reinforced concrete beams subjected to repeated loading into the inelastic range. The principal aim of the overall study is to evaluate the performance of lapped splices and to recommend design procedures for seismic loading. In the first phase of the project, eight half-scale pilot beams and fourteen full-scale beams were tested. The large beams had #8 and #10 main bars. All beams contained two bars spliced in the constant moment regions of beams loaded with two third-point loads. The main variables were the amount and distribution of stirrups, the load history, and the splice length. Most beams were subjected to repeated loads without reversals. The tests show the importance of closely spaced stirrups along the entire length of the splice because damage penetrated well into the splice region under repeated loading beyond yield (67 ksi in these tests). At least twice as many stirrups should be used as the maximum effective amount recommended by ACI Committee 408 for monotonic loading. Not much damage and capacity reduction were observed for repeated loads up to about 80% of the yield level (67 ksi) of the bars.

● *See **Preface,** page v, for availability of publications marked with dot.*

These conclusions are tentative because the investigation is continuing and many additional tests are planned. A few pilot tests have included the effects of load reversals and the results indicate that significantly more damage occurs than for repeated nonreversed loads. Other pilot tests indicate that the presence of shear improves splice performance because the moments are not equal at the ends of the splice and damage does not penetrate at the same rate from the two ends.

● **6.6-131** Yeroushalmi, M. and Harris, H. G., **Behavior of vertical joints between precast concrete wall panels under cyclic reversed shear loading**, *Structural Models Lab. Report M78-2*, Dept. of Civil Engineering, Drexel Univ., Philadelphia, Mar. 1978, 96.

An exploratory study of the seismic resistance of "plain" vertical joints in large panel precast concrete buildings has been made using small-scale direct models. Twenty-eight 1/16-scale joint assemblies consisting of a story high vertical joint and two horizontal joints at top and bottom were tested under monotonic and cyclic shear simulating earthquake loading. The main parameters investigated were the effect of joint concrete strength, amount and yield strength of reinforcement perpendicular to the joint, and the width-to-thickness ratio of the joint. The strength and stiffness characteristics of the joints were studied by comparison of the hysteresis plots and the effects of cyclic reverse loading on the monotonic load-deflection behavior. Typical observed behavior of these joints shows "pinched" hysteresis curves indicating very low energy-absorbing capabilities.

6.7 Nondeterministic Dynamic Behavior of Nonlinear Structures

● **6.7-1** Matsushima, Y., **Nonlinear random response of single-degree-of-freedom system with general slip hysteresis** (in Japanese), *Transactions of the Architectural Institute of Japan, 276*, Feb. 1979, 53–58.

This paper concerns the analytical estimation of the probabilistic properties of the stationary random response for a single degree-of-freedom system with "general slip" hysteresis, when subjected to Gaussian white excitation. Expressions obtained in previous papers are presented for bilinear and pure-slip characteristics because such restoring forces are two extreme cases of the general slip hysteresis. Theoretical expressions have been digitally simulated. Except when either the input intensity is quite low or the plastic stiffness ratio is close to unity, the analytical solution of the R.M.S. displacement coincides with sufficient accuracy with the corresponding experimental displacement. Excluding the cases where either the input intensity or the plastic stiffness ratio is close to zero, the theoretical R.M.S. plastic deformations are in good agreement with simulated estimates. Theoretical values of the expected accumulated plastic deformation agree quite well with simulated ones over the wide range of related parameters. In addition, it has been verified that the response of the system where both the bilinear and the pure slip hysteresis loops are combined can be predicted by the solution of the equivalent general slip characteristic.

● **6.7-2** Wen, Y.-K., **Stochastic seismic response analysis of hysteretic multi-degree-of-freedom structures**, *Earthquake Engineering & Structural Dynamics*, **7**, 2, Mar.-Apr. 1979, 181-191.

Analytical study of random vibration of nonlinear multidegree-of-freedom (MDF) systems is generally difficult. This is particularly true for MDF inelastic systems because of the highly nonlinear and hereditary behavior of the restoring force. On the other hand, to obtain the response statistics using a step-by-step Monte Carlo simulation requires a large sample and could be very costly. The purpose of this paper is to present a practical analytical-empirical method for an MDF yielding system. The method is based on a substitute structure (SS) concept in which the SS parameters are determined from empirical results of single degree-of-freedom systems, i.e., each element in the system is replaced by a linear counterpart with ductility-dependent stiffness and damping. Based on a linear random vibration response analysis, the statistics of the maximum response (ductility) of each element are obtained by iteration. Numerical examples are given for multistory buildings with deteriorating (reinforced concrete frame) or nondeteriorating (steel frame) restoring forces. Comparisons with empirical results are qualitatively satisfactory. The main advantage of this method is that it requires relatively insignificant computation time, e.g., 1 sec of execution time on the IBM 360-75 system for an eight-story steel frame.

● **6.7-3** Iyengar, R. N., **Inelastic response of beams under sinusoidal and random loads**, *Journal of Sound and Vibration*, **64**, 2, May 22, 1979, 161–172.

A new analytical model is suggested for the hysteretic behavior of beams. The model can be used directly in a response analysis without the necessity of locating the precise point where the unloading begins. The model can efficiently simulate several types of realistic softening hysteretic loops. This is demonstrated by computing the response of cantilever beams under sinusoidal and random loadings. Results are presented in the form of graphs for maximum deflection, bending moment, and shear.

● **6.7-4** Grossmayer, R. L., **Elastic-plastic oscillators under random excitation**, *Journal of Sound and Vibration*, **65**, 3, Aug. 8, 1979, 353–379.

● *See **Preface**, page v, for availability of publications marked with dot.*

Simulation studies reveal that the elastic-plastic oscillator cannot be successfully treated by any linearization procedure. In order to compute the main response quantities, such as the yielding increment, the permanent set, the dissipated energy, and the crossing rates, a so-called two-state approach is suggested. Maintaining the separation between the elastic and plastic parts of the response as originally proposed by Karnopp and Scharton, the author obtains one linear equation for each state. The fundamental step, then, is to set up a conditional probability density for the plastic state variable under Gaussian stationary or nonstationary white noise excitation. The yielding duration is found to be of half-normal distribution. Numerical results demonstrate the approach and the range of parameters where the approach can be successfully applied.

● 6.7-5 Iemura, H., **Earthquake response of stationary and deteriorating hysteretic structures**, Dept. of Civil Engineering, Kyoto Univ., Kyoto, Japan, May 1977, 194.

This report concerns investigations of the earthquake response of stationary and deteriorating simple hysteretic structures through numerical simulations, theoretical analyses, and examinations of earthquake accelerograms. Plastic deformation of simple structures with bilinear and curved hysteresis loops subjected to artificial earthquakes is simulated on a digital computer as a moving average of the displacement time-history, eliminating the elastic component of vibration. The shapes of the hysteresis loops are found to have significant effects on the plastic deformation of relatively short-period structures.

Plastic deformation of the perfectly elastoplastic structures which yield in one direction is estimated analytically for each yielding by replacing the kinetic energy at the yielding point with the equivalent plastic deformation. The analytical results are compared with simulated results to check the applicability of the technique. It is found that estimation of the plastic deformation in the random response is satisfactory. The technique is also applied to an equivalently linearized vibrational system to obtain the accumulated plastic deformation when the system is subjected to stationary white noise excitation. Two different types of equivalent linearization techniques are adopted for theoretical discussions and statistical prediction of earthquake hysteretic response. The relation between the two techniques is examined, and it is concluded that they have like expressions of equivalent linear parameters. Stationary and nonstationary root mean square responses of bilinear hysteretic structures are analytically predicted by the linearization techniques. Using the results, the probability distribution of the maximum hysteretic response is also predicted through pure-birth and envelope methods. Monte Carlo simulation performed on a digital computer verifies the applicability of the techniques within admissible ranges of error.

Strong-motion earthquake accelerograms are investigated to find the deteriorating hysteretic properties of the restoring force of a reinforced concrete structure. Equivalently linearized and hysteretic models for the fundamental mode of the structure are examined to determine whether they can describe the observed response. Models with time-dependent parameters are found to match the response with suggestions of the degrading stiffness and energy dissipation capacity of the structure. A new simple model, in which equivalent structural parameters degrade with decreasing residual strength, is proposed to represent general deteriorating hysteretic structures. Response analysis of the proposed model points out the significant effects of time-dependent structural capacities on the earthquake response both in the amplitude and frequency components.

● 6.7-6 Grossmayer, R. L. and Iwan, W. D., **Some observations on the effective period and damping of randomly excited yielding systems**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 533–542.

In this study, a bilinear hysteretic system is used as a simple model of a yielding structure. The response of the system to a broad-band Gaussian random excitation is investigated by means of digital computer simulations. These simulation results are intended to serve as a guide in developing both simplified and reliable analytical theories for the earthquake response of yielding systems.

● 6.7-7 Casciati, F., Faravelli, L. and Cobetti, A., **Permanent deformations of rigid-plastic structures subject to random dynamic loads**, *Engineering Structures*, **1**, *3*, Apr. 1979, 139–144.

The probabilistic analysis of the inelastic displacement response for simple rigid-plastic structures subject to dynamic loads is considered. The paper presents a method for approximating the probability density function of the residual displacement at any time t. The procedure is based on the filtered Poisson process theory. This model aims to idealize the input stochastic process (i.e., the loading function) and to describe the output process (i.e., the residual displacement). The extension to elastic-perfectly plastic structures is immediate. A numerical example shows the computational aspects of the method.

● 6.7-8 Riddell, R. and Newmark, N. M., **Statistical analysis of the response of nonlinear systems subjected to earthquakes**, *UILU-ENG 79-2016, Structural Research Series 468*, Dept. of Civil Engineering, Univ. of Illinois, Urbana, Aug. 1979, 291.

The dynamic response of single degree-of-freedom nonlinear systems subjected to earthquake motions is considered in order to derive factors for constructing inelastic design spectra, and to evaluate the effect of damping combined with inelastic behavior and the influence of the type of material nonlinearity on inelastic response. Inelastic response spectra for elastoplastic systems with 2%, 5%, and 10% damping, and for bilinear and stiffness degrading systems with 5% damping are computed for a number of frequencies ranging from about 0.03 Hz to 35 Hz, for ductility values from 1 to 10, and for ten strong-motion earthquake records. A statistical procedure is developed to analyze the data; from this analysis, factors for deriving the characteristic trapezoidal design spectrum are obtained. Such factors reflect, in an explicit manner, the effect of the various parameters considered.

● 6.7-9 Soda, S. and Tani, S., **Dynamic analysis of elastic-plastic structures by statistical equivalent linearization method** (in Japanese), *Transactions of the Architectural Institute of Japan*, 283, Sept. 1979, 68–75.

In the statistical analysis of the dynamic behavior of elastic-plastic structures, the equivalent linearization method is useful and practical because of its theoretical simplicity. However, the method does not lead to accurate results when a structure exhibits large deflection and extreme nonlinearity. In this paper, the cause of this inaccuracy is examined and the method is modified for use in the analysis of extremely nonlinear structures. Nonstationary RMS response to stationary and nonstationary white noise is calculated by means of digital simulation and by a method of the author's. It is shown that both sets of results coincide fairly well and that a small difference in the spectral characteristics of the excitation in the long-period region does not cause a difference in the displacement response.

● 6.7-10 Casciati, F. and Faravelli, L., **Safety analysis for random elastic-plastic frames in the presence of second-order geometrical effects**, *Environmental Forces on Engineering Structures*, 499–512. (For a full bibliographic citation, see Abstract No. 1.2-28.)

The aim of this paper is to perform a reliability analysis of elastic-plastic frames taking into account the geometrical nonlinearities of the structural behavior. Particularly emphasized are the modifications required in the approach usually used in the safety analysis of structures fully described by a first-order model.

6.8 Soil-Structure Interaction

● 6.8-1 Irie, Y., Kitagawa, Y. and Osawa, Y., **Study on soil-building interaction effects during earthquakes (Part 1) experiments at Huchinobe and evaluation of their results by fundamental model** (in Japanese), *Transactions of the Architectural Institute of Japan*, 278, Apr. 1979, 67–80.

A mathematical model is developed for a soil-structure system. Experimental results from a simple test of a soil-structure system are compared with theoretical results calculated by means of the mathematical model.

● 6.8-2 Little, R. R. and Raftopoulos, D. D., **Vertical soil-structure interaction effects**, *Bulletin of the Seismological Society of America*, 69, *1*, Feb. 1979, 221–236.

An analytical expression describing three-dimensional vertical soil-structure interaction effects is developed using Laplace and Hankel transformation techniques. By means of these transformation techniques and the normal mode theory of vibration, an N-mass structural model is coupled to an elastic halfspace representing the earth. The resulting interaction equation is solved by numerical iteration techniques for a model of a nuclear power plant subjected to actual earthquake ground excitation. The effects of the soil-structure interaction are evaluated by comparing free-field acceleration spectrum response curves with similar curves determined from the foundation motion. These effects are found to be significant for structures typical of modern nuclear power plants subjected to seismic ground motions.

● 6.8-3 Finn, W. D. L., **Role of foundation soils in seismic damage potential**, *Third Canadian Conference on Earthquake Engineering*, Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 77–115.

The seismic response of a structure depends on the stability of the foundation soils, the local ground motions, and soil-structure interaction. The role of each of these factors is discussed, and their relationship to building code provisions for the computation of seismic forces in structures is considered. The report provides an understanding of the basis and limitations of existing code provisions. A thorough analysis of recommendations for including the effects of soil-structure interaction in seismic design is given.

● 6.8-4 Reddy, D. V., Arockiasamy, M. and Haldar, A. K., **Nonlinear seismic response analysis of a gravity monopod using MODSAP-IV**, *Third Canadian Conference on Earthquake Engineering*, Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1343–1363.

The development and application of a modified SAP-IV program, MODSAP-IV, for the nonlinear seismic response analysis of a large-diameter, offshore, prestressed concrete gravity platform-foundation system are presented. The soil-structure system is idealized by (1) isoparametric plane strain and (2) variable-number-nodes thick shell and three-dimensional isoparametric elements. The thickness of the soil elements in the plane strain model is varied parametrically until its fundamental frequency matches that

● See ***Preface***, *page v, for availability of publications marked with dot.*

obtained from the three-dimensional formulation. The added water mass is assumed equal to the mass of water displaced and is lumped at the nodes of the tower and the caisson. The nonlinear behavior resulting from shear deformation of the soil is considered by a method of equivalent linearization following the procedure of Seed and Idriss, and the equations of motion are solved using step-by-step direct integration to obtain an approximate solution. The stiffnesses and damping values are made compatible with effective shear strain amplitudes at the soil element centroids. Final values of the soil element stiffness and damping properties are determined by an iterative plane-strain analysis based on a modification of SAP-IV which provides for variable soil damping as opposed to constant damping. Using beam elements in the superstructure, the authors calculate responses to determine the effect of soil-structure interaction.

● **6.8-5** Novak, M. and Hindy, A., **Seismic response of buried pipelines,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 177–203.

This paper examines the response of pipelines in a homogeneous medium and in two different media separated by a vertical boundary. Fault crossing is not considered. The paper summarizes research conducted at the Univ. of Western Ontario. The theoretical study is formulated in terms of deterministic and random vibrations. The focus is on dynamic soil-pipe interaction. Excitation by seismic waves travelling along the pipe under different angles of incidence and random response to seismic loading which is not fully correlated are considered.

● **6.8-6** Ray, D. and Reed, R. C., **Dynamic response of surface and embedded rectangular foundations for body and surface wave excitations,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 241–261.

A class of important soil-structure interaction phenomena, namely, wave scattering (diffraction), is introduced and accounted for by a simple concept of filtering. The dynamic response spectra of rigid, massless surface and embedded rectangular foundations welded to an elastic halfspace and subjected to generally obliquely incident body (SH, SV, and P) waves and horizontally propagating surface (Rayleigh) waves are presented as functions of an equivalent dimensionless frequency parameter for various angles of incidence. The results indicate that both the directivity (angle of incidence) and the type of incident seismic wave have a marked effect on the nature and magnitude of the foundation response. Torsional response is greatest for horizontally propagating SH waves, while rocking response becomes predominant for horizontally propagating SV and Rayleigh waves for rectangular foundations with the usual shallow ratio of embedment depth to lateral width. In all cases, the translational components of response undergo marked decreases, with the increase in the dimensionless frequency parameter, from the corresponding free-field motions. The influence of the embedment-lateral width ratio on the dynamic response of the foundations is also investigated. It is found that the translational motions decrease and the rotational motions increase with an increase in this ratio. The need to conduct research to allow the adaptation of the filtering concept to seismic excitations is discussed. The accuracy of the results predicted by the filtering concept is compared with those obtained by numerical solution of associated mixed boundary-value problems. The cost of computation by the concept for the practical range of interest of the dimensionless frequency parameter is only a fraction (-1:1000) of that needed to solve the associated mixed boundary-value problem.

● **6.8-7** Chen, W. W. H. and Chatterjee, M., **Impedance approach and finite element method for seismic response analysis of soil-structure systems,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 263–287.

Vertical seismic soil-structure interaction analyses are performed using the impedance approach and the direct finite element method (FLUSH) for a deeply embedded nuclear power plant. Important parameters affecting seismic soil-structure interaction analysis, such as foundation embedment, superstructural modeling, and input motions, are investigated. It is found that the effects of the details of structural modeling and foundation input motion on the total vertical foundation motion is insignificant. The use of the surface impedance function gives a very conservative structural response as compared to that obtained using the embedded impedance function. The impedance approach and the direct finite element method are found to predict slightly different vertical peak accelerations. The peak spectral acceleration at the top of the reactor building obtained by FLUSH is approximately 20% lower than that obtained by the impedance approach. The difference in the spectral amplitude can be attributed to two causes: (1) material damping is not considered in the impedance approach; and (2) the two-dimensional characteristics of the FLUSH solution may give a spectral response lower than that of a three-dimensional solution. These results suggest that the major contribution to the difference in the vertical FLUSH and the impedance approach analysis may be attributed to the two-dimensional characteristics of the FLUSH analysis.

● **6.8-8** Beliveau, J.-G., Ellyin, F. and Chandrasekhar, P., **The effect of soil-structure interaction on the dynamic behavior of a nuclear power plant** (Effet de l'interaction

● *See* ***Preface****, page v, for availability of publications marked with dot.*

sol-structure sur le comportement dynamique de centrale nucleaire, in French), *Third Canadian Conference on Earthquake Engineering*, Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 223–239.

The behavior of a relatively flexible structure resting on stiff soil or bedrock should be insensitive to the effects of soil-structure interaction, whereas the influence should be more significant for a stiff structure resting on a relatively flexible soil. A nuclear power plant is characterized by two masses representing the containment and internal structures with appropriate springs and dashpots. Lateral and rocking motions are considered with equivalent springs and dashpots. All coupling is in the mass matrix for this simple four degree-of-freedom model. The behavior of the damped natural frequencies and corresponding damping ratios and mode shapes is studied. The cyclic response is further investigated for a given set of parameters yielding identical resonant frequencies. Finally, a comparative evaluation of non-normal modes and normal modes based on a proportional damping model is made.

● **6.8-9** Yamada, Y., Takemiya, H. and Kawano, K., **Random response analysis of a non-linear soil-suspension bridge pier,** *Earthquake Engineering & Structural Dynamics*, **7**, *1*, Jan.-Feb. 1979, 31–47.

The structure analyzed in this paper is the tower and pier system of a long-span suspension bridge. The tower shaft is modeled to allow the decomposition of classical normal modes in order to reduce higher modes. The pier is assumed to be a rigid body capable of translational and rocking motion, being reacted by the surrounding soil compliance that is derived from a continuum mechanics approach. Linear and nonlinear soil and structural dynamic interaction is dealt with by random vibration theory using the linearization technique and complex modal analysis. Primary interest is placed on the investigation of the dynamic characteristics of the total interaction system and the root-mean-square response with change of the soil condition and input excitation level. Also discussed is the approximate response analysis, using classical normal modes for the interaction system for purposes of practical design.

● **6.8-10** Kim, J. B., Singh, L. P. and Brungraber, R. J., **Pile cap soil interaction from full-scale lateral load tests,** *Journal of the Geotechnical Engineering Division, ASCE*, **105**, *GT5*, Proc. Paper 14571, May 1979, 643–653.

The results of full-scale lateral load tests on three groups of six piles were published in the January 1976 issue of this journal as Proc. Paper 11849. Additional full-scale lateral load tests were performed on the same pile groups and piles after removing 4 in. of soil from under the pile caps to study the effect of the soil directly under the pile caps on the lateral capacity of pile groups. In the range of 16.66 kips/pile to 33.33 kips/pile lateral loads, the absence of the soil under the pile caps increased significantly both the lateral deflections of the pile groups and the bending moments in the piles.

● **6.8-11** Day, S. M. and Frazier, G. A., **Seismic response of hemispherical foundation,** *Journal of the Engineering Mechanics Division, ASCE*, **105**, *EM1*, Proc. Paper 14339, Feb. 1979, 29–41.

A time domain finite element method is used to investigate the response to seismic waves of rigid, three-dimensional, embedded foundations. The method eliminates the influence of artificial grid boundaries by completing the transient solution prior to the arrival of any nonphysical reflections. The accuracy of the numerical procedure is examined by comparing it with analytic solutions; discrepancy is less than 5% at all frequencies up to β/a in which β = the shear wave speed of the embedment medium; and a is the foundation radius. For a hemispherical foundation, the scattering of vertically incident S waves reduces the higher frequency horizontal translation of the foundation compared with the free-field motion but introduces a significant rocking component that is absent from the free field.

● **6.8-12** Kitamura, Y. and Sakurai, S., **Dynamic stiffness for rectangular rigid foundations on a semi-infinite elastic medium,** *International Journal for Numerical and Analytical Methods in Geomechanics*, **3**, *2*, Apr.-June 1979, 159–171.

This paper considers the dynamic steady-state force-displacement relationships (complex stiffness) for rectangular rigid foundations resting on a semi-infinite medium, consisting of homogeneous, isotropic, linear elastic materials. The foundations are considered to be excited under harmonic vertical and rocking vibrations. These conditions result in mixed boundary value problems which cannot be easily solved by analytical approaches. Therefore, a numerical method is proposed in this paper. The method is based on quite simple equations and is straightforward in computation compared with other methods. Although the proposed method gives only approximate solutions, it is satisfactory for engineering practices; the solutions become highly accurate for a small value of $\omega B/V_s$. The results obtained by the method are compared with those of other methods. The effects of length/width ratio and the area of the contact plane of the foundations are also discussed.

● **6.8-13** Iwasaki, T. and Kawashima, K., **Seismic analysis of a highway bridge considering soil-structure interaction effects,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering*, New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 73–84.

● *See **Preface**, page v, for availability of publications marked with dot.*

In analyzing the seismic behavior of highway bridges constructed on soft soil deposits, it is important to take account of soil-structure interaction effects. In this paper, the seismic response of a bridge pier-foundation is investigated using earthquake acceleration records measured simultaneously on the pier crest and on the ground surface near the bridge. Four motions are used in the analysis; two were induced by two earthquakes with magnitudes of 7.5 and 6.6, respectively, and two were induced by their aftershocks. In the former two earthquakes, the maximum accelerations were 186 and 438 gals on the ground surface, and 310 and 230 gals on the pier top, respectively. Analyses of the frequency characteristics of the motions showed that the predominant frequencies of the pier-foundation were nearly identical with the fundamental natural frequency of the subsoil. Analyses of microtremors measured at the sites revealed that the natural frequency of the pier-foundation system is higher than the fundamental natural frequency of the subsoil. Analytical models are formulated to calculate the seismic response of the pier-foundation assuming the subsoil and pier-foundation to be a shear column model with an equivalent linear shear modulus and an elastically supported beam on the subsoil, respectively. Bedrock motions are computed from the measured ground surface motions and then applied to the bedrock of the analytical model. The seismic responses of pier-foundation are thus calculated and are compared with the measured records, giving good agreement.

● **6.8-14** Priestley, M. J. N., Park, R. and Heng, N. K., **Influence of foundation compliance on the seismic response of bridge piers,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 569-587.

This paper summarizes the results of dynamic analyses of a number of single-stem and double-stem bridge piers responding to a range of earthquake ground motions, including natural and synthetic earthquake records. The influence of foundation flexibility is modeled by an "extended leg" analogy and by a more refined approach in which the soil is replaced by an equivalent spring system. A bilinear moment-curvature loop is assumed to model the plastic hinge behavior. The curvature ductility factor demand of bridge piers with different foundation flexibilities is determined and compared with the rigid foundation case.

● **6.8-15** Kamil, H., Hom, S. and Kost, G., **An overview of soil-structure interaction procedures with emphasis on the treatment of damping,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 623-632.

This paper presents an overview of the different procedures for analyzing soil-structure interaction currently in use in the industry, with emphasis on the treatment of damping in these procedures. The description of procedures is followed by results from analyses of typical emergency feedwater and auxiliary buildings. Conclusions and recommendations are then presented.

● **6.8-16** Chen, P. C., Deng, D. Z. F. and Birkmyer, A. J., **Consideration of dynamic stress concentrations in the seismic analysis of buried structures,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 165-174.

The seismic analysis of buried structures such as pipes, conduits, and tunnels has been customarily performed using the one-dimensional wave propagation theory. In this approach, the buried structures are assumed to conform to the deformations of the surrounding soils during earthquakes. Consequently, the response accelerations, displacements, and velocities of the surrounding soil medium determined without considering the buried structures are imposed on these structures as design requirements. Another approach to the seismic analysis of buried structures is to include the soil-structure interaction using either the continuum or the finite-element methods. The soil-resistance functions can be either frequency-dependent or frequency-independent. Both these methods consider the soil to be an elastic, homogeneous, and isotropic medium. The methods do not consider the layered soil medium and the possible effect of stress concentrations caused by the existence of voids inside the buried structures, nor do the two approaches include the effects of diffraction and scattering of seismic waves on structures. The significance of these effects can be assessed once the dynamic stress concentration factors on the structures are determined.

● **6.8-17** Ellis, B. R., **A study of dynamic soil-structure interaction,** *Proceedings, The Institution of Civil Engineers,* Part 2, **67**, Paper 8233, Sept. 1979, 771-783.

This paper presents the results from two experiments that illustrate the difference between the properties of a structure on a rigid foundation and the properties of the same structure on a flexible foundation. The effects of soil-structure interaction and the consequences of neglecting soil-structure interaction in a dynamic analysis are discussed.

● **6.8-18** Dasgupta, G. and Chopra, A. K., **Dynamic stiffness matrices for viscoelastic half planes,** *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM5,* Proc. Paper 14888, Oct. 1979, 729-745.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

Analytical expressions and numerical results are presented for the complex-valued, dynamic (frequency dependent), flexibility influence coefficients for a homogeneous, isotropic, linearly viscoelastic halfspace in plane strain or generalized plane stress. These influence coefficients, defined for uniformly spaced nodal points at the surface of the halfplane, are obtained from solutions of two boundary value problems, associated with harmonically time-varying stresses uniformly distributed between two adjacent nodal points. Numerical values for these coefficients are presented for a viscoelastic halfplane of constant hysteretic material. A method is developed to determine from these results the dynamic stiffness matrix, associated with the nodal points at the base of a surface supported structure, for the halfplane. The resulting dynamic stiffness matrix is shown to be superior compared to the one determined from an available procedure, which is based on solutions of displacement boundary value problems for the halfplane.

● **6.8-19** Mei, C. C. and Foda, M. A., **An analytical theory of resonant scattering of SH waves by thin overground structures,** *Earthquake Engineering & Structural Dynamics,* 7, 4, July-Aug. 1979, 335-353.

Scattering of SH-waves in a halfspace with simple overground structures is studied analytically. For two-dimensional structures, such as shells, shear walls, and a slab-bridge over a river, the method of matched asymptotics is used for sinusoidal waves that are long in comparison with the thickness of the structures. Resonance features are deduced analytically and calculated numerically for various incidences and other parameters.

● **6.8-20** D'Appolonia Consulting Engineers, **Seismic input and soil-structure interaction,** *NUREG/CR-0693,* Div. of Systems Safety, U.S. Nuclear Regulatory Commission, Washington, D.C., Feb. 1979, 367.

The purpose of the study is to assess the adequacy of some engineering assumptions made in the definition of seismic input and methods used for the analysis of seismic soil-structure interaction of nuclear power plants. The primary goal is to determine the range of applicability of the acceptance criteria presented in Section 3.7 of the United States Nuclear Regulatory Commission Standard Review Plan (SRP) and to note the specific instances when the criteria given in the SRP require modification or analysis on a site-specific basis.

● **6.8-21** Matlock, H. and Foo, S. H. C., **Simulation of lateral pile behavior under earthquake motion,** Dept. of Civil Engineering, Univ. of Texas, Austin, July 1978, 74.

A dynamic analysis for lateral soil-pile behavior has been developed and implemented in a beam-column computer program called SPASM (Seismic Pile Analysis with Support Motion). The analytical method makes it possible to study the lateral response of soil-pile systems under earthquake ground motion. Wave loadings and mudslide effects may also be considered. The single pile member, represented in the analysis by a discrete-element mechanical model, is restricted to linearly elastic behavior. Simplified superstructure effects can be simulated by increased stiffness along the pile member within the structural system and by coupled rotational restraints at appropriate joints. All input data for the pile, soil, and motion can be freely varied along the length. Stability and accuracy are maintained in the dynamic analysis by using an implicit (Crank-Nicolson) type of numerical solution. The soil-pile coupling at each node along the embedded length of the pile is represented by a multi-element assemblage of friction blocks, springs, and dashpots which facilitates the examination of hysteretic soil-pile interaction under earthquake loading. The present nonlinear-inelastic soil support model allows either degradation or hardening of resistance as a function of deflection and of the number of reversals of deflection in the range beyond an initially elastic condition. Furthermore, the formation of gaps is allowed in order to properly represent the expected soil-pile interplay in the upper layers of the soil. In the current method of analysis, separately computed lateral ground displacements are used as input excitation, freely variable in space and time. During a solution, these lateral ground displacements are simulated by moving the bases of the supports with respect to the point of zero deflection of the pile. The computer program is formulated to allow interfacing with either a superstructure program or a free-field motion program. Several example problems are presented to demonstrate the validity and the uses of the method of analysis and the computer program. Further developments of the current analytical procedure are recommended. Other potential applications of the method are also discussed.

● **6.8-22** Windham, J. E. and Curtis, J. O., **Effect of backfill property and airblast variations on the external loads delivered to buried box structures,** *Technical Report S-78-5,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, June 1978, 203. (NTIS Accession No. AO 58669)

The purposes of this code calculation study are to (1) determine the effect of selected soil backfill property variations and surface loading options on the high overpressure, airblast-induced ground shock environments experienced by a hypothetical shallow-buried structure, and (2) provide a tangible example for structural analysts of the type of backfill-structure interaction information that can be obtained for use in buried structure vulnerability assessments. This report (1) outlines the plan of analyses, (2) describes the finite element code calculations, (3) presents the results of the calculations, (4) reports comparative analyses of the effects of the independent variables, and (5) discusses the implications of these results. The analyses are

● *See **Preface,** page v, for availability of publications marked with dot.*

essentially limited to the results of the six HONDO code calculations that are the key elements of this study.

A supplementary study is reported in an appendix and a simple method for producing the rigid body motion of a buried box structure is presented in the references. This method is applied to the 1-MT, 300-psi (20.7-bar) dense backfill case. The calculated vertical motion of the structure is found to be in good agreement with the HONDO-code-calculated structure motion time histories.

● 6.8-23 Matlock, H. et al., **SPASM 8: a dynamic beam-column program for seismic pile analysis with support motion,** Fugro, Inc., Long Beach, California, Jan. 15, 1979, 179.

Laterally loaded piles under earthquake and other dynamic loadings are analyzed by a dynamic beam-column program called SPASM 8 (Seismic Pile Analysis with Support Motion, version 8). This report constitutes the documentation of the program. Discrete-element mechanical analogs are used to represent the pile-soil system. The pile itself is linearly elastic. A fully nonlinear-inelastic, hysteretic, and degrading soil support model has been developed and implemented in the program. A gap element is also devised and included in the soil model to simulate separation of the soil from the pile under cyclic loading, which generally occurs near the mudline. Separately computed lateral ground displacements are used as input excitation. Simplified superstructure effects can be simulated by increasing stiffness and mass for the pile above the mudline, and by the application of rotational restraints at appropriate nodes along the pile. An implicit (Crank-Nicolson) type of numerical operator is employed to formulate the dynamic solution. This results in excellent stability and accuracy. A detailed description of the structure and the flow of the program SPASM 8 is presented in this report. An example problem, using both a sine-wave and a numerical description of the lateral ground displacements, is solved to illustrate the method of input coding and to serve as a practice problem for user familiarization.

● 6.8-24 Hindy, A. and Novak, M., **Earthquake response of underground pipelines,** *Earthquake Engineering & Structural Dynamics,* 7, 5, Sept.-Oct. 1979, 451-476.

The seismic response of underground pipelines is investigated theoretically with dynamic soil-pipe interaction taken into consideration. A lumped-mass model of the pipe is employed with the soil reactions derived from static and dynamic continuum theories. The soil is assumed to be homogeneous or composed of two different media separated by a vertical boundary. Axial and bending stresses in the pipe caused by traveling waves are examined. An extensive parametric study indicates that the axial stresses in the pipe are much higher than the bending stresses. In a homogeneous medium, soil-pipe interaction reduces the stresses in the pipe compared to those calculated ignoring interaction. In a soil composed of two different media, the pipe stresses are highest close to the boundary and can exceed those predicted when interaction is ignored.

● 6.8-25 Scott, R. F., **Cyclic static model pile tests in a centrifuge,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. II, OTC 3492, 1979, 1159-1168.

Scaling relations for soil studies indicate that certain model behaviors will correctly represent those of the prototype if the model is subjected to an acceleration proportional to the model scale. The most convenient way of accomplishing this is to perform model tests in a large centrifuge. Lateral cyclic load tests were carried out on a 1/100-scale instrumented model pile embedded in a saturated sandy silt at 100 g in a centrifuge. The history of displacements and moments is presented and discussed in this paper. An analysis is presented to explain the observed softening behavior of the pile.

● 6.8-26 Stevens, J. B. and Audibert, J. M. E., **Re-examination of p-y curve formulations,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3402, 1979, 397-403.

In the analysis of piles supporting offshore structures, the key element in predicting the response to lateral loads is the determination of the appropriate lateral load-deformation relationships (p-y curves) for the soil. The present practice of constructing p-y curves is based on the results of lateral load tests on instrumented piles and strength-deformation characteristics of the soil. A study was undertaken to compare the results from lateral load tests on piles up to 59 in. in diameter driven in soft to medium clays to the results predicted using the above methods of constructing p-y curves. In general, it is found that the predicted pile deflections are significantly greater than the observed deflections and that the maximum bending moments are underestimated. Two factors are identified as sources of the differences. The first is the assumed linear dependence of the soil-deformation characteristics on pile diameter, and the second is that the lateral soil resistance at shallow depths is greater than is given by the empirical methods. Based on these results, modifications are suggested to the present methods of constructing p-y curves.

● 6.8-27 Veletsos, A. S. and Boaz, I. B., **Effects of soil-structure interaction on seismic response of a steel gravity platform,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3404, 1979, 413-425.

● *See **Preface**, page v, for availability of publications marked with dot.*

After a brief review of the principal effects of soil-structure interaction on the response of structures subjected to earthquakes, a simple practical procedure is presented for evaluating these effects. The procedure is used to study the response of a proposed 400-ft steel gravity platform (for a 300-ft water depth location), and the results of the study are discussed. The structure investigated consists of three large-diameter legs of tubular construction interconnected by a truss-type bracing system and supported on three circular pads.

● **6.8-28** Harada, T., Kubo, K. and Katayama, T., **Dynamic soil reactions (impedance functions) including the effect of dynamic response of surface stratum (Part 1),** *Seisan-Kenkyu,* 31, *9,* 1979, 21-24.

● **6.8-29** Harada, T., Kubo, K. and Katayama, T., **Dynamic soil reactions (impedance functions) including the effect of dynamic response of surface stratum (Part 2),** *Seisan-Kenkyu,* 31, *10,* 1979, 1-4.

● **6.8-30** Dasgupta, S. P. and Rao, N. S. V. K., **Dynamic response of strip footings on elastic halfspace,** *International Journal for Numerical Methods in Engineering,* **14,** *11,* 1979, 1597-1612.

The dynamic response of strip footings resting on a soil medium, idealized as an elastic halfspace, is obtained using the finite element discretization technique with constant strain rectangular elements consisting of 4CST elements. Boundary stresses have been computed using a combination of Rayleigh wave absorbing boundaries and standard viscous boundaries. The influences of contact pressure distributions at the footing-soil interface—mass and frequency ratios on the dynamic response of a strip footing—are studied. Effects of embedment, static surcharge, nonhomogeneity, and nonlinear constitutive relations are shown. Results are compared with the existing solutions and are presented graphically.

● **6.8-31** Priestley, M. J. N., Park, R. and Heng, N. K., **Influence of foundation compliance on the seismic response of bridge piers,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, 22-34.

This paper summarizes the results of dynamic analyses of some single-stem and double-stem bridge piers subjected to a range of earthquake ground motions, including both actual and simulated earthquake records. The influence of foundation flexibility was modeled by an "extended leg" analogy and by a more refined approach in which the soil is replaced by an equivalent spring system. A bilinear movement-curvature loop is assumed to model the plastic hinge behavior. The curvature ductility factor demand of bridge piers with different foundation flexibilities is determined and a comparison is made with the rigid foundation case.

● **6.8-32** Wang, L. R.-L., O'Rourke, M. J. and Pikul, R. R., **Seismic vulnerability, behavior and design of buried pipelines,** *SVBDUPS Project Technical Report 9,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Mar. 1979, 137.

This is the final report of the first phase in a research project entitled "Seismic Vulnerability, Behavior and Design of Underground Piping Systems (SVBDUPS)." The report presents the seismic damage and response behavior of general buried pipelines, describes vulnerability evaluation and design criteria of buried simple piping systems, and proposes recommendations for further studies. The investigation is centered on the simplified analysis and quasi-static analysis approaches for determining the axial strains and relative joint displacements or rotations caused by seismic shaking. The use of these approaches is justified by observations that axial strains are predominant and the effects of pipeline inertia forces are negligible. To verify the assumptions and limitations of the analyses, the ground motion characteristics of the San Fernando earthquake are studied in detail. To fulfill the analysis requirements, the related soil parameters are discussed. The seismic vulnerability and design of simple buried piping systems is evaluated by use of a seismic risk analysis using data for Albany, New York, and a failure criterion for buried water pipes is proposed. Finally, a case study is performed for the Latham water distribution system using the procedures outlined above.

Based on a parametric study, the seismic responses of buried piping systems are found to be influenced by the physical properties of the pipes and joints, the geotechnical properties at the site, and the seismological parameters of the geographical region. The following general conclusions can be made. (1) An upper bound for axial strain in the pipe is the maximum ground strain. This is based upon the assumptions that the pipeline inertia effects are negligible and the pipeline has negligible axial stiffness relative to the ground. (2) The upper bound on relative joint displacement is the product of the maximum ground strain and the pipe segment length. This is based upon the assumptions that inertia terms are negligible but the pipe segments between joints are infinitely rigid relative to the ground. (3) The maximum axial strains and maximum relative joint displacements of an actual pipeline in a seismic environment are within these two bounds. Their magnitudes depend on the relative stiffnesses of pipes and joints and the surrounding medium. The axial strain will be greatest for continuous pipelines in which relative joint displacements are absent. (4) The pipe strains and relative joint displacements are higher for pipelines surrounded by relatively soft soils. (5) The seismic responses of buried simple pipelines are critically influenced by the slope of the ground displacement time history (i.e., the maximum ground velocity). Since this report applies primarily to simple piping systems

● *See **Preface,** page v, for availability of publications marked with dot.*

in simple geological environments, several recommendations are outlined for extending the study to general piping systems with junctions or intersections in general geological environments.

● 6.8-33 Savidis, S. A. and Richter, T., **Dynamic response of elastic plates on the surface of the half-space,** *International Journal for Numerical and Analytical Methods in Geomechanics,* 3, *3,* July–Sept. 1979, 245–254.

A "mixed method" for the dynamic calculation of foundations on soil is presented in this paper. The halfspace is computed analytically and the foundation is modeled using finite elements. The method is very well suited for the solution of three-dimensional problems, including interaction. Numerical results for a simple case involving a dynamically loaded elastic plate are presented, and the influence of plate stiffness is studied.

● 6.8-34 Veletsos, A. S., **Soil-structure interaction for buildings subjected to earthquakes,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 51, 20.

It is generally recognized that the dynamic response of a structure supported on soft soil may be substantially different from the response of a similarly excited, identical structure supported on firm ground. Two factors are responsible for this difference: (1) The dynamic characteristics of the flexibly supported structure are different from those of the rigidly mounted structure; and (2) part of the vibrational energy of the flexibly supported structure is dissipated by radiation of waves and hysteretic action in the underlying soil. There is no counterpart of the latter effect in a rigidly supported structure. After reviewing the principal effects of soil-structure on the dynamic response of structures subjected to ground motions, a simple practical procedure will be presented for evaluating these effects. The procedure utilizes response spectra applicable to fixed-base systems. A brief account also will be given of how the concepts underlying this approach have been used recently in the formulation of recommended seismic design provisions for buildings.

● 6.8-35 Vannucchi, G., **Reinforced concrete cylindrical piles subjected to horizontal forces: diagrams for ultimate strength design** (Pali cilindrici in C. A. soggetti a forze orizzontali: abachi per il calcolo a rottura, in Italian), *Giornale del genio civile,* 117, *4–6,* Apr.–June 1979, 141–154.

A rapid method is presented for the calculation of the ultimate lateral resistance of cylindrical piles of reinforced concrete driven into saturated cohesive or cohesionless soils. The behavior of the pile at failure is briefly described. The response of the soil is examined according to Broms's theory and the hypothesis about the calculation of the ultimate limit state of sections on reinforced concrete according to the FIP/CEB recommendations making use of the dominions of strength. Diagrams are furnished which present families of curves derived from Broms's theory for failure.

● 6.8-36 Alpan, I. and Leshchinsky, D., **Vibrating machines on large, flexible, elastically-supported slabs,** *Publication 243,* Faculty of Civil Engineering, Technion–Israel Inst. of Technology, Haifa, Mar. 1978, 29.

A method is presented to evaluate the response of vertically vibrating machines placed on large, flexible, and elastically supported slabs. The treatment of the deflection problem is based on Hertz' theory, i.e., linear elastic spring supports (a "Winkler" subgrade). The theory of the elastic halfspace is used to relate its material deformation parameters with the unit spring reaction of the subgrade. A model of the vibrating system is constructed based on suitable modifications of the theory of vibrating discs on an elastic halfspace, and the response of the system is determined by use of an analogy with a simple resonator (a lumped-parameter system). Two cases concerning applied unbalanced force were considered with the amplitude either constant or frequency-dependent. The material parameters required for evaluation, including some relevant empirical data, are briefly discussed.

● 6.8-37 Wang, L. R.-L., **Quasi-static analysis formulation for straight buried piping systems,** *Seismic Vulnerability, Behavior and Design of Underground Piping Systems, Technical Memorandum 3,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, July 1978, 23.

The quasi-static governing equilibrium equations are developed for the axial response of buried pipelines subjected to earthquakes. The formulation is general and includes such parameters as variable elasticity, segment lengths and cross sections of pipes, variable joint stiffnesses, variable soil-resistant characteristics, and end conditions. Variations of seismic wave form, propagation velocity, and delay time can be incorporated into the numerical procedure.

● 6.8-38 Morgan, J. R., Hall, W. J. and Newmark, N. M., **Response of simple structural systems to traveling seismic waves,** *UILU-ENG-79-2015, Structural Research Series 467,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, Sept. 1979, 114.

Presented in this report are the results of studies of the dynamic response of a simple structural system with coupled translational and rotational degrees-of-freedom subjected to ground motion containing translational and rotational components. The investigation was carried out to

● *See **Preface**, page v, for availability of publications marked with dot.*

assess current building code procedures and to arrive at bounds on the interrelationship between torsional and translational response.

● **6.8-39** Johnson, J. J., **SOILST: a computer program for soil-structure interaction analysis,** *GA-A15067*, General Atomic Co., San Diego, California, Apr. 1979, 138.

SOILST is a computer program designed to perform soil-structure interaction analysis. Two types of analysis can be performed: time history analysis by direct integration, and the determination of equivalent modal damping ratios for the coupled soil-structure system. The superstructure dynamic characteristics are defined by the structure's fixed-base eigensystem. The behavior of the supporting soil is defined by frequency-independent impedance functions. The theory, user's manual, and listing of the program are contained in the report.

● **6.8-40** Koori, Y., Yamamoto, S. and Shimizu, N., **Three-dimensional dynamic analysis of soil-structure system by thin layer element method (Part 3: numerical examples in comparison with existing results and numerical examples for seismic analysis of deeply embedded buildings),** *Transactions of the Architectural Institute of Japan, 283*, Sept. 1979, 37-48.

● **6.8-41** Kishida, H. and Nakai, S., **Analysis of a laterally loaded pile with non-linear subgrade reaction** (in Japanese, with English summary), *Transactions of the Architectural Institute of Japan, 281*, July 1979, 41-55.

An analytical method is presented to predict the behavior of a laterally loaded pile taking into consideration the failure of the soil. The behavior of the soil-pile system analyzed by the proposed method was compared with the results of four model pile tests and with the results of twelve full-scale tests conducted in the field.

● **6.8-42** Chen, C. C., Ariman, T. and Katona, M., **A finite element analysis of buried pipelines under seismic excitations,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation* 133-142. (For a full bibliographic citation, see Abstract No. 1.2-16.)

In this paper, time-history responses of buried pipelines during seismic excitations are investigated by utilizing a finite element solution technique, the SAP IV computer program for a cross-sectional model in which the seismic wave travels in the perpendicular direction to the pipe; and a longitudinal model in which the pipe axis is aligned with the seismic wave direction. In order to represent soil-structure interaction in a realistic way, both the pipe and soil are incorporated into the models. It appears that delay time may have a considerable effect on the displacements of the buried pipe. The effect of pipe end conditions on axial forces and displacement histories are also studied.

● **6.8-43** Nelson, I. and Weidlinger, P., **Effect of local inhomogeneity on the dynamic response of pipelines,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 63-82. (For a full bibliographic citation, see Abstract No. 1.2-16.)

Pipes located in transition zones between soil types suffer disproportionate damage when subjected to seismic shaking. In an earlier work, the authors considered the dynamic axial response of long segmented pipelines induced by incoherent seismic ground motion, with homogeneous soil conditions assumed. This paper extends the authors' previous work to include local inhomogeneity. The results are expressed in terms of appropriate spectra. In general, a local inhomogeneity may contribute to a change in pipe response in three different ways. In the case of wave propagation, there will be a local variation in delay time. Inhomogeneity will cause a variation in the free-field waveform at adjacent segments. Finally, the soil stiffness will vary from soft to firm material. In general, all three effects will occur simultaneously; however, to help understand the phenomena, each effect is considered separately. The major cause of large joint motion appears to be the change in soil stiffness.

● **6.8-44** Niyogi, B. K. and Sethi, J. S., **Testing and analysis of buried piping under applied loads,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 153-160. (For a full bibliographic citation, see Abstract No. 1.2-16.)

The study of soil-pipe interaction and the design of underground piping are inexact sciences because of the assumptions that must be made regarding soil conditions and because of the practical necessity to simplify greatly the theoretical mathematical relationships between the many variables. Several different empirical approaches are reviewed and compared with the results of full-scale testing. Empirical relations are seen to be very conservative. The test results of this paper can be used directly. A better analytical approach is also shown which reduces the excessive conservatism of the empirical relations.

● **6.8-45** Cole, B. W., Ritter, C. J. and Jordan, S., **Structural analysis of buried reinforced plastic mortar pipe using the finite element method,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 83-103. (For a full bibliographic citation, see Abstract No. 1.2-16.)

Structural analyses of large-diameter, buried, reinforced plastic mortar (RPM) pipe are performed. A multi-level analysis has been devised which employs integrated, two-dimensional, finite element models as an alternative to large-scale, three-dimensional analyses which require the use of brick elements. The integrated approach employs

● *See **Preface**, page v, for availability of publications marked with dot.*

plane strain models, curved thin shell models, and two-dimensional axisymmetric models with imposed asymmetric displacement loadings. A combination of general purpose and special finite element programs are employed.

● **6.8-46** Johnson, J. J., **Soil structure interaction analysis for the US NRC Seismic Safety Margins Research Program,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 3/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In order to evaluate the conservatism in the seismic design of nuclear power plants, the hazards resulting from seismically induced accidents are to be determined from a probabilistic system model of a nuclear power plant. This Seismic Safety Margins Research Program (SSMRP) is sponsored by the U.S. Nuclear Regulatory Commission. The program has been organized into several phases; the initial phase is to be completed by May 1980. One of the results of Phase I of the SSMRP will be an overall system model composed of a series of functions representing the various stages in the seismic analysis and design process, i.e., seismic input, soil-structure interaction, major structural response, structural subsystem response, fragility of structures and components, and the event/fault tree chain leading to core melt. Each function defines a "best estimate" value and its variation with respect to differing physical parameters. In addition, an assessment of the accuracy of the mathematical models to represent the physical phenomenon is made. Exercising the overall systems model leads to an estimate of the probability of release of radioactive material as a function of earthquake size. The actual value of the probability of release of radioactive material computed in the SSMRP Phase I has little validity in an absolute sense as a result of the incompleteness of the model, the lack of pertinent data, particularly in the area of fragility of structures and components, and its anticipated wide variation. However, the probability of release and its variation with varying physical and modeling parameters is of value in assessing the relative importance of the various links in the seismic analysis and design methodology chain and their uncertainty in the result. These results will help direct the allocation of research funds in future phases of the SSMRP. This methodology developed for Phase I of the SSMRP will be exercised on the Zion Nuclear Power Plant, Zion, Illinois.

A report on the progress of the soil-structure interaction project is to be presented. The initial portion of this task concentrates on defining the state-of-the-art in the analysis of the soil-structure interaction phenomenon, an assessment of those aspects of the phenomenon which significantly affect structural response, and recommendations for future development of analytical techniques and their verification. A series of benchmark analytical and test problems for which analytical techniques may be evaluated are also sought. This assessment is to be performed in the context of nuclear power plant structures, i.e., massive stiff structures arranged functionally on a particular site. The "best estimate" methodology will be utilized to develop transfer functions for the overall systems model. These transfer functions will operate on the free-field ground motion yielding the structural base mat response and selected in-structure response quantities for the particular site being analyzed. The transfer functions will depend on a number of parameters, e.g., soil configuration, soil material properties, frequency of the excitation, structural properties, etc. A limited comparison of alternative methods of analysis including a nonlinear analysis will be performed.

● **6.8-47** Mukherjee, S. N., **Non-linear analysis of a deeply embedded power plant building subjected to earthquake load,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 6/9, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The dynamic seismic response of a power plant building on deeply embedded foundations is investigated. The building and soil are simulated by a mathematical model using two-dimensional finite elements. Nonlinear soil properties and linear building properties are assumed. Considered in the study are soil stiffness and shear wave velocity, the presence of several soil layers with different material properties, and an assumed yield condition for the soil. An earthquake time history input motion at bedrock is used. Comparison of the foundation response spectra determined by nonlinear analyses shows decreasing accelerations in the lower frequency range, which would have a favorable effect on power plant building and component dimensions. Plastic areas which form under the foundation slab over a period of time are also investigated.

● **6.8-48** El-Tahan, H. and Reddy, D. V., **Seismic response of the "cut-and-cover" type reactor containments considering nonlinear soil behavior,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 7/9, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes parametric studies of dynamic soil-structure interaction for the "cut-and-cover" reactor concept. The dynamic loading considered is a horizontal earthquake motion. The high-frequency ranges, which must be considered in the study of soil-structure interaction for nuclear power plants, and the nonlinearity of soil behavior during strong earthquakes are adequately taken into account. Soil nonlinearity is accounted for in an approximate manner using a combination of the equivalent linear method and the method of complex response with complex moduli. The structure considered is a reinforced concrete containment for an 1100 MWe power plant, buried in a

● *See **Preface**, page v, for availability of publications marked with dot.*

dense sand medium. Studied are the containment shape, the relative stiffness of the containment and the medium, the depth of burial of the containment, the relative stiffness of the medium and the filling material, the thickness of the backfill jackets, the isolation of the containment using energy-absorbing jackets around the containment, and the type of surrounding medium (sand and rock).

● 6.8-49 Tanaka, H., Ohta, T. and Uchiyama, S., **Experimental and analytical studies of a deeply embedded reactor building model considering soil-building interaction (part I)**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(a), Paper K 7/8, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes the dynamic characteristics of a deeply embedded reactor building model derived from experimental and analytical studies that considered soil-structure interaction. The building model is made of reinforced concrete, with two stories above ground and a basement resting on a sandy gravel layer at a depth of 3 m. Backfill was placed around the building up to ground level. The building model is simplified and reduced to about 1/15 of the prototype. It has a bearing wall system for the basement and the first story and a frame system for the second story. The effects of embedment on the dynamic properties of the soil-structure interaction system are investigated by comparing the results of forced vibration tests before and after placement of the backfill. The shaking device was located on the second floor of the building, and horizontal and vertical forces were generated. After the vibration tests, several seismographs were installed on the building and also buried in the surrounding soil for continuous earthquake observations.

The fundamental natural frequency and the second frequency before the backfill placement, obtained from resonance curves, were 10.4 Hz and 16.5 Hz, respectively; and the fundamental frequency after the placement of the backfill was 12.3 Hz. Thus, it can be seen that the frequency after placement of the backfill increased as compared with the frequency before placement of the backfill. The amplitude, however, decreased between a half and a quarter. From the test results, it can be postulated that the backfilled sand will increase the restraint effect of the building and the radiation damping to the surrounding soil.

Because the dynamic characteristics of this type of rigid structure are significantly influenced by the soil properties, the test results before backfill placement were examined by means of a swaying-rocking analytical model. The complex stiffess of the soil-structure system was evaluated, and it was confirmed that the complex stiffness of a soil-structure system is dependent upon frequency, as is generally recognized. The estimated complex stiffness agreed fairly well with that obtained by use of H. Tajimi's vibration admittance theory in the range of dimensionless frequency less than 2.0. Simulation analyses of the forced vibration tests before backfill placement were performed. It was found that the analytical results obtained using a mathematical model that included the effect of radiation damping were in good agreement with the experimental results.

● 6.8-50 Chen, W. W. H., Chatterjee, M. and Day, S. M., **Seismic response analysis for a deeply embedded nuclear power plant**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(a), Paper K 7/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

One of the important aspects of the seismic-resistant design of nuclear power plants is the evaluation of the seismic soil-structure interaction effect resulting from design earthquakes. The soil-structure interaction effect can initiate rocking and result in different soil motions compared to the free-field motions, thus significantly affecting the structural response. Two methods are generally used to solve the seismic soil-structure interaction problems: the direct finite element method (FLUSH) and the substructure or impedance approach. This paper presents the results of the horizontal seismic soil-structure interaction analysis using the impedance approach and the direct finite element method for a deeply embedded nuclear power plant.

The impedance functions and input motions which characterize the scattering and the radiative processes involved in a complete soil-structure interaction analysis are investigated using a finite element method developed by Day. This method employs time-centered explicit integration in time and because it does not require the assembling of a stiffness matrix, the storage requirements are smaller compared with the storage requirements of conventional finite element methods. Important parameters affecting seismic soil-structure interaction analysis such as foundation embedment, backfill, soil material damping, and soil layering are investigated. It is found that the impedance approach and the direct finite element method predict similar peak horizontal and rocking accelerations. However, at the top of the reactor building, the peak spectral acceleration obtained by the direct finite element method is approximately 30% lower than that obtained from the impedance approach.

The difference in the spectral acceleration can be attributed to two causes: (1) material damping is not considered in the impedance approach, (2) the two-dimensional characteristics of the FLUSH solution may give a spectral response lower than that of a 3-D analysis. In the 2-D model, the waves are usually trapped within the slice and energy attenuation is mainly a result of material damping. Previous comparisons of the results of 2-D and 3-D horizontal seismic soil-structure interaction analyses

● *See **Preface**, page v, for availability of publications marked with dot.*

indicate that the 3-D solution may result in response values up to 30% higher than those obtained from the 2-D solution. Also, it has been found that the effect of soil material damping on the structural response obtained from the impedance approach is insignificant. These results suggest that the major contribution to the difference in the horizontal FLUSH and the impedance approach analysis may be attributed to the two-dimensional characteristics of the FLUSH analysis.

● 6.8-51 Deans, J. J. and Tang, J. H. K., **Seismic stresses in buried piping of arbitrary configuration,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 7/3, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents a finite element approach for use in the study of the stresses induced by earthquakes in the underground piping systems of nuclear power plants. The stiffness matrix for a pipe on an elastic foundation is developed. The induced loads are calculated based on the imposed free-field soil strain or on building movements. The seismic strain caused by various types of seismic waves and an arbitrary angle of incidence is also considered. In addition, it is recognized that, although the analytical techniques have been developed to a high level of sophistication, not much is known about such basic soil parameters as subgrade reactions and frictional resistance. It is recommended that a parametric study always be conducted to investigate the effects of variations in these values with respect to the stresses that result from seismic ground motion since this can easily be done by use of a computer program.

● 6.8-52 Takemori, T. et al., **Comparison of soil-structure interaction by different ground models,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 5/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In this paper, dynamic soil-structure interaction analyses for PWR power plant facilities are performed, using the parameters of Young's moduli, soil dampings, and three earthquake waves having different frequency characteristics. Two methods are used in the analysis: (1) a response analysis of the lumped mass model with swaying-rocking springs of soil and (2) a deconvolution analysis by means of a finite element soil model. Results of these analyses are discussed, and a modification of soil damping is proposed to bring the analytical results in closer agreement with the generally observed tendency concerning the amplified acceleration around the foundation.

● 6.8-53 Lam, P. C. and Scavuzzo, R. J., **Torsional structural response from free-field ground motion,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 5/6, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The torsional response of structures subjected to the action of both free-field torsional inputs and external torque is investigated. By expanding the work of Scanlan, both lateral and torsional foundation inputs caused by a traveling shear wave are derived from the free-field point motion. These free-field torsional motions are used as the basis of numerical studies. Responses for different soil stiffness and structural characteristics are studied, as well as different dynamic models. In one dynamic model, the structure is coupled to the soil using a compliance spring matrix, and, in the second model, the structure is coupled to an elastic halfspace. Results of these two basic models are compared and found to be in good agreement. Torsional structural response caused by torsional inputs is compared with lateral response caused by modified lateral inputs to determine the significance of torsional excitation on the seismic response of structures. Numerical results show that these torsional seismic loads are as large or larger than those from modified lateral inputs.

● 6.8-54 Ettouney, M. M., Brennan, J. A. and Aguero, A. A., **Seismic design method for arbitrary propagating waves,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 5/7, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents a complete analysis and design method for propagating waves which accounts for the multi-incident angle (wave number) case. The proposed method is presented in two steps. The first step is to generalize the concept of the design response spectra so that it can represent the seismic accelerations caused by incident waves with multi-wave numbers. This is done by introducing the concept of the three-dimensional design spectrum (3-DS). The 3-DS is based on the assumption that the spectrum is a surface instead of a line, as in the conventional case. This surface is a function of the frequency as well as the wave number of the seismic excitation. A simple and logical relation between the 3-DS and the conventional spectrum is presented, and it is shown that the conventional spectrum is a limiting case of the 3-DS. The second step is to present an accurate and simple method for analyzing a given plane strain soil-structure system for the 3-DS input motion. The solution is based on a semianalytical approach which solves the elastic wave propagation equation of a layered soil subjected to a surface harmonic impulse. The rigid body motion of the footing is then enforced and the dynamic soil flexibility coefficients are determined. The transfer functions between the free field and the building are obtained for any required wave number (incident angles) at the free field. The method is then repeated for as many wave numbers (incident angles) as the 3-DS requires. The final frequency spectra, building accelerations, and building response spectra could then be obtained by a simple numerical integration technique. Some practical dynamic soil-structure interaction cases are studied using both the 3-DS approach and the conventional method of analysis. Comparisons between the structural responses in both cases show considerable differences, especially in the case of structural rocking response where higher amplitudes were obtained from the 3-DS approach.

● **6.8-55** Waas, G. and Weber, W., **Soil structure interaction analyses by different methods,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 6/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper examines appropriate methods for seismic soil-structure interaction analysis. A circular PWR building is analyzed using a plane strain finite element model, an axisymmetric finite element model, and a lumped parameter model. The structure weighs 1600 MN, is about 65 m high, 60 m in diameter, and very stiff. It is founded 18 m below the ground surface on alluvial deposits which are several hundred meters thick. The plane strain finite element analysis is of the type commonly used in the U.S.A., e.g., with the computer program FLUSH. The analysis utilizes the transmitting boundaries developed by Waas to account for radiation damping. The control motion is assumed at the ground surface in the free field. The seismic input at the base of the model is obtained from the control motion by one-dimensional deconvolution. Strain-compatible dynamic soil properties are computed by equivalent linear analysis. The axisymmetric finite element analysis (with non-axisymmetric loading) is similar to the plane strain analysis. It also uses a transmitting boundary and the same input motion computed by deconvolution.

In the lumped parameter model, the flexibility and damping resulting from the subgrade is represented by soil springs and dashpots based on halfspace theory. The spring constants are adjusted for embedment. The control motion is directly applied as support acceleration according to common use in Germany. The lumped parameter model yields structural accelerations much larger than both the finite element models. However, results similar to those of the axisymmetric finite element analysis can be obtained by the lumped parameter model when the control motion is not directly used as support acceleration, but modified using one-dimensional deconvolution to account for the variation of the free field ground motion with depth.

The development of an equivalent two-dimensional finite element model for a basically axisymmetric system is very difficult. At least some advance knowledge of the response of the actual three-dimensional system is required when the equivalent width and length of the embedded structure is to be selected. In general, it is not possible to match the resonance frequencies of the rigid body modes of the structure as well as their damping values. The quality of the two-dimensional finite element results depends strongly on the availability of three-dimensional solutions to similar problems and on the skill and intuition of the analyst.

● **6.8-56** Wolf, J. P. and Obernhuber, P., **Travelling wave effects in soil-structure interaction,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 5/1, 12. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Traveling-wave phenomena are normally not considered in soil-structure interaction. Only vertically incident S- and P-waves are commonly assumed. To determine the influence of this basic assumption, the response of a massless basemat, a massless rigid structure, a basemat with mass, a rigid structure with mass, and a single mass-spring system connected to a basemat with mass is parametrically analyzed for harmonic and transient excitations for all wave forms (SH-, P-, SV- and Rayleigh waves). Results for the same structures, calculated for the standard vertically incident body waves of the same amplitudes, are compared. In addition, the influence of the introduction of the concept of a soft first story, which can also deform inelastically, and of the partial separation of the base mat from the soil is examined. For illustration, a reactor building and the through-soil coupling of a reactor and a reactor auxiliary building are examined in detail, using the J 145 record of the 1971 San Fernando earthquake as a traveling wave. Compared to the standard assumption, the filtering effect of the kinematic interaction leads to a smaller response in all points of the massless rigid structure for all frequencies and for all angles of incidence of the SH-waves. This does not hold, however, for P- and SV-waves, as the induced rocking of the seismic input motion is about twice as large as the torsional motion corresponding to SH-waves. Adopting the concept that the vertical and horizontal earthquakes correspond to P- and SV-waves, respectively, the P- and SV-waves are governing for angles of incidence of 40°-70°. For structures with mass, however, nonvertically incident SH-waves can dominate the design, as the radiation damping of the torsional motion is considerably smaller than that associated with the translation. Although the filtering effect of Rayleigh waves is pronounced because of the comparatively low velocity, the horizontal motion is governing for all points at higher elevations. This is caused by the retrograde motion of this wave, which forces the horizontal motion corresponding to the translation to be in phase with that of the rocking. The obvious advantages for horizontal excitation of a structure with a soft first story do not apply in general to the rocking input motion. The traveling-wave effects dominate the in-structure response spectra for lower frequencies in many locations of the reactor building.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● **6.8-57** Gantayat, A. N. et al., **Investigation of the influence of interaction of two adjacent structures on their responses,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 6/8, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The paper presents a lumped mass/soil spring approach for evaluation of the influence of interaction between two adjacent structures on their responses resulting from an aircraft impact. The interacting structures were idealized as lumped mass cantilevers supported on independent soil springs and connected by coupling springs. The constants for independent soil springs were developed using a classical halfspace approach, taking into account the embedment effects where applicable. The coupling stiffness matrix was derived by computing first the flexibility coefficients based on the geometric relationship of the two footings resting on the surface of a homogeneous, isotropic, linear elastic halfspace, and then inverting it. A numerical technique for the computation of the coupling terms of the flexibility matrix was developed.

Two separate analyses were performed for a nuclear power plant, first, to determine the influence of interaction between the reactor building and the auxiliary building A and, second, to determine the influence of interaction between the reactor building and the auxiliary building B. Auxiliary buildings A and B differed in size and geometry, but both were considerably less massive than the reactor building. The interaction analyses were carried out for an aircraft impact loading applied at the top of the reactor building in the horizontal and vertical directions separately. Floor response spectra at selected elevations of both buildings were evaluated. The results showed that the peak spectral response at several nodes of the reactor building was slightly smaller for the coupled case as compared to the uncoupled case. The corresponding response of the auxiliary building A was found to be somewhat more significant. Similar results were obtained for interaction between the reactor building and auxiliary building B.

On the basis of the results of the above analyses, general conclusions are presented regarding the influence of structure-to-structure interaction on the peak values of the structural response and the frequencies at which these peaks occur. The importance of the distance between the two structures and their relative masses on the structural response is also discussed. The paper concludes with recommendations for future work.

● **6.8-58** Del Grosso, A., Stura, D. and Vardanega, C., **Building-soil-building interaction in seismic analysis of nuclear power plants,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 6/6, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Since a nuclear power plant is normally composed of several buildings with different dynamic characteristics clustered in a fairly small area, the mutual interaction effect can be significant for the total response evaluation when a seismic excitation is of concern. Although relevant work has been done in the field of the single building-soil interaction problem, both by numerical methods and theoretical approaches, the problem above has not been completely investigated. Furthermore, in the majority of the cases, the studies carried out for the building-to-building interaction problems assume a plane geometry, with the two buildings aligned according to the direction of the seismic motion.

In the present paper, a truly three-dimensional representation of the problem is taken into account and a parametric study is presented in order to obtain an appropriate description of the phenomenon. In particular, this treatment has the advantage of allowing the detection of those components of the motion, such as transverse displacement, rolling, and twisting, that are necessarily hidden by a plane idealization. Two computer codes were implemented for this purpose. The first one is derived from a semi-analytical procedure based on a solution of the wave propagation problem in terms of a Fourier expansion of the space variables. A computer program associated with this solution was already written by Gazetas for two-dimensional situations for a single foundation. The second one is a finite element program which uses a cylindrical coordinates extension of the Lysmer-Waas consistent boundary. This method was developed and utilized by Kausel for the case of a single foundation. Both programs make the assumptions of a linearly elastic, horizontally layered soil with hysteretic damping. The buildings are idealized as 4-degree-of-freedom systems with respect to an underlying rigid foundation mat. The dynamic response of the bases of the buildings is shown in the form of plots of the amplification functions. A comparison is established with the results obtained by the program FLUSH.

● **6.8-59** Mueller, C. and Furrer, H., **Structure-to-structure interaction analysis for a nuclear power plant,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 6/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The effect of the mutual dynamic interaction on the buildings, the so-called through-soil coupling is analyzed for a BWR power station. Because of the various buildings involved and their geometrical arrangement, a three-dimensional approach is used. The five most important buildings considered are modelled by the lumped-mass technique. The coupling terms are derived from a static analysis of a large 3D finite element model of the supporting soil. The nearly linear material behavior of the underlying Triassic rock allows use of linear elastic finite elements. For reasons

● *See **Preface,** page v, for availability of publications marked with dot.*

of comparison, a 2D analysis was performed for only one section. In this 2D analysis, the material characteristics are treated as the pseudo nonlinear material.

● 6.8-60 Jain, V. K., Nayak, G. C. and Jain, O. P., **Analysis of conical shell foundation on elastic subgrade**, *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings*, NEM Chand & Bros., Roorkee, India, 1979, IV-197-207.

A finite element analysis is developed for an axisymmetric shell on an elastic foundation using curved parabolic elements. The coefficients of subgrade modulus have been approximated from actual elastic solid solutions. The effect of toes and the variation of the coefficients of subgrade modulus are reported in detail for various cases of conical shell foundations having half-vertex angles of 37.5°, 45.0°, 52.5°, and 60.0° and subjected to vertical loads. For lateral loads, the formulation of a shell on an elastic foundation has been extended to include the harmonic analysis of a general axisymmetric shell. The study is useful for optimizing the shape of the foundation structure and for preparing the design charts.

● 6.8-61 Wood, L. A., **Simple boundary elements in soil-structure interaction applications**, *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings*, NEM Chand & Bros., Roorkee, India, 1979, VII-1-6.

Consideration is given to the coupling of simple boundary elements, based upon the classical equations of elasticity of a semi-infinite, homogeneous continuum; the soil is represented by standard structural finite elements. The use of two computer programs, RAFTS and LAW-PILE, which incorporate this technique in the solution of soil-structure interaction problems is illustrated with respect to the measured behavior of actual structures. The four examples chosen encompass raft and pile foundations, laterally loaded piles, and sheetpile walls, and include nonhomogeneous, transversely isotropic soil deposits together with nonlinear soil response.

● 6.8-62 Parikh, S. K. and Pal, S. C., **Parametric analysis of laterally loaded concrete piles in different soils using boundary elements**, *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings*, NEM Chand & Bros., Roorkee, India, 1979, VII-71-75.

An analysis, using a pile as a bending element and soil as a boundary element, is presented for the horizontal displacement and rotation of a vertical pile subjected to lateral loading and moment and situated in an ideal elastic soil mass. Parametric studies based on different subgrade reaction coefficients and different pile slenderness ratios have been carried out to establish simple mathematical expressions for different influence factors. A wide range of values have been covered for both free-head and fixed-head piles. The results indicated here agree reasonably well with those reported from measurements on full-scale piles.

● 6.8-63 Khatua, T. P., Pattanayak, A. K. and Gupta, A. K., **Dynamic analysis of buried structures subjected to shock loads**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. M, Paper M 6/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A systematic method is presented for computing the dynamic structural response of buried structures to shock loads; interaction between the structure and the surrounding soil medium is considered. The complexity of the problem is increased because of the high frequency content of the shock load. The purpose of this paper is to describe how the finite element method is successfully used to compute structural responses caused by shock loads with a high frequency content. The method for selecting the various critical parameters (e.g., element size, time step of integration, frequency content, etc.) used in the analysis is also described in detail. Finally, a full-scale practical problem is solved to demonstrate the effectiveness of the proposed method.

● 6.8-64 Holzlohner, U., **The use of an equivalent homogeneous half-space in soil-structure interaction analyses**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. M, Paper M 10/3, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In analyses of seismic soil-structure interaction, the soil often is assumed to be an elastic body. The solution procedure is lengthy if the heterogeneity of the soil is strictly considered. If the soil is taken as a homogeneous elastic halfspace, existing solutions can be used. There are solutions for some simple layered systems, too. However, it is often not easy to correlate the variation of the soil properties with depth, as found by measurements, to those of ideal systems. The purpose of the paper is to show how to make use of the existing solutions.

At most real sites, the shear modulus will usually increase with depth. The increase may be continuous or discontinuous as in the case of layered systems. Compared to the homogeneous halfspace, systems with increasing stiffness with depth produce larger amplitudes. Layered systems exhibit distinct resonance peaks. They are flattened, however, if dissipative damping is assumed, which is reasonable in the case of earthquakes. Then, the responses of systems with continuous and discontinuous increases of stiffness with depth become similar to each other. Based on the behavior of a layered medium and on the behavior of systems with continuously increasing stiffness, a simple

● *See **Preface**, page v, for availability of publications marked with dot.*

procedure for application to all kinds of stiffness increases with depth has been developed.

By use of averaging processes, equivalent material quantities are evaluated by examining the actual variation of the material properties with depth. Similar to the method of calculation of residual settlements, the stress variation with depth is used as a weight curve in the averaging processes. As the variation of the characteristic stresses below the footing depends on the type of motion, the weight curves for vertical translation, horizontal translation, and rocking differ. The calculated equivalent quantities can be inserted directly in the spring functions of the impedances of the halfspace. The damping functions have to be more intensely modified in order to take into account the main effect of the heterogeneity, which is the reduction of radiation damping.

● **6.8-65** Matthees, W., **Some considerations on the dynamic structure-soil-structure interaction analysis,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 10/3a, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A mixed method has been developed for the approximate analysis of soil-structure or structure-soil-structure interaction problems caused by earthquakes. In order to produce comparable results for shallow and deep soils subjected to the same earthquake excitation (accelerogram) at the lower bedrock boundary, the analysis is performed in two steps: (1) calculating by means of a one-dimensional deconvolution of the complex transfer function and the response of the upper interior boundary of a layered soil-system which is connected at its top to a soil-structure system and (2) performing a complete interaction analysis of the surface soil-structure system using an interior boundary excitation of the calculated response from step 1. A low enough depth for the soil-structure system must be chosen so as to exclude interaction effects down to the layered soil system's interior boundary. The method can be adapted for use with the computer program FLUSH.

● **6.8-66** Gazetas, G. and Roesset, J. M., **Vertical vibration of machine foundations,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15050, Dec. 1979, 1435-1454.

The paper presents the results of an analytical study of vertical vibrations of massive strip foundations excited by constant-force or rotating-mass type oscillators and placed on the surface of linearly hysteretic soil layer on rock. A semianalytical method based on a direct solution of the wave equations in terms of displacements and accounting for the exact physical conditions at the rough layer interfaces and the soil surface is briefly presented. The results shown illustrate the importance of the layer depth, the rock compliance, and the foundation mass on the dynamic vertical response of the foundation.

● **6.8-67** Kausel, E. et al., **Seismically induced sliding of massive structures,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT12,* Proc. Paper 15065, Dec. 1979, 1471-1488.

Massive structures are usually analyzed for the effects of earthquake loading by procedures that give conservatively large envelopes of loads and acceleration. When these envelopes are used to evaluate the sliding stability of the structures, the calculated factors of safety are unrealistically low. This study starts with an evaluation of the appropriate values of shear strength at the foundation-soil interface under both saturated and unsaturated conditions. Then a mathematical model is developed that includes the rotational, horizontal, and vertical degrees-of-freedom of the structure, as well as the sliding at the base. The model is used for a range of structural configurations, soil properties, and earthquake accelerograms. The results of the analyses show that sliding can be initiated at very low levels of seismic excitation, but this critical level of excitation required to cause sliding is higher than the critical level of excitation predicted by the simple pseudostatic methods of analysis now in use.

● **6.8-68** Masao, T. et al., **Earthquake response of nuclear reactor building deeply embedded in soil,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 7/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Forced vibration tests were conducted on a 5 x 5 x 5 m concrete cubic model, weighing 240 t and having a base 3.75 m under the surface of the ground. Accelerations were measured at the top of the model, at the ground surface, and in the ground. Earth pressures were measured at the bottom and sides of the model. Two analytical methods (the lumped mass method and the finite element method with transmitting boundary) were used to calculate results for comparison with the experimental results. The lumped mass method was used under the following assumptions. (1) The free-field soil was modeled by a mass and a shear spring system. (2) To generate acceleration at the base of the model, a free-field motion corresponding to the level determined during the experiments was adopted. (3) To consider the effects of interaction between the soil and the side wall of the model, resistances proportional to the relative velocity and displacement were used. For the finite element analysis, the following assumptions were used. (1) The irregular zone was modeled by means of quadrilateral axisymmetric elements under a nonaxisymmetric load. (2) The layered zone was modeled by means of an axisymmetric element having a transmitting boundary and subjected to a nonaxisymmetric load. Materials were modeled as linear viscoelastic media. (3) Damping was modeled by means of complex stiffness moduli.

From a comparison of the experimental and analytical results, it was found that (1) the shapes of the time histories were in agreement, but that the maximum accelerations determined in the analyses were slightly greater that those determined in the experiments and (2) the response spectra agreed in both shape and value. Additionally, there were no significant differences in the seismic response found by means of the lumped mass method and those found by means of the finite element method. Both the experimental and analytical studies indicate that, by increasing radiational damping, embedment has an effect on the seismic response of such deeply embedded structures as nuclear reactor buildings. It is concluded that the method presented in this paper is useful for analyzing such cases.

● 6.8-69 Werner, S. D. et al., **Structural response to traveling seismic waves**, *Journal of the Structural Division, ASCE*, **105**, *ST12*, Proc. Paper 15059, Dec. 1979, 2547–2564.

A new methodology for analyzing the three-dimensional response of soil-structure systems to traveling seismic waves is described and used to analyze a single-span bridge subjected to incident plane SH-waves. The analytical results demonstrate the importance of traveling wave effects and show how the excitation frequency and direction of incidence of the seismic waves influence the three-dimensional response characteristics of this bridge-soil system.

● 6.8-70 Gomez-Masso, A. et al., **Soil structure interaction in different seismic environments**, *UCB/EERC-79/18*, Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 55. (NTIS Accession No. PB 80 101 520)

Presented is a plane-strain method for soil-structure interaction analysis in a generalized seismic environment. The method involves the superposition of the free field motions and the interaction motions. The free field is modeled as a horizontally layered viscoelastic medium and the seismic environment may consist of a combination of S, P, and Rayleigh waves. The soil-structure system is modeled with viscoelastic finite elements, transmitting boundaries, viscous boundaries, and a 3-dimensional simulation. Comparative analyses of the same structure are conducted for an input of R waves and for vertically propagating S and P waves in a rock site and a sand site. In the rock site, the R waves produce higher peak horizontal spectral acceleration up to 25% and a significant rocking effect at points away from the center of gravity of the structure. However, the S and P waves show a higher peak vertical spectral acceleration by up to 15% at the center of the structure. In the sand site, a similar horizontal response is obtained, but a higher vertical response is obtained at the center of the structure for S and P waves.

6.8-71 Fedyakova, S. N., **Spectral analysis of building earthquake response in Petropavlovsk-Kamchatsk** (Spektral'nyi analiz kolebanii zdanii pri zemletryaseniyakh v g. Petropavlovske-Kamchatskom, in Russian), *Voprosy inzhenernoi seismologii, 19*, 1978, 11–27.

Techniques for using spectral response characteristics in soil-structure interaction studies are discussed in the light of available experimental information. A computational formula is analyzed for use in determining seismic forces, with allowance for the spectral characteristics of the strongest expected earthquake, and for use in determining the dynamic parameters of the soil foundation-structure system.

● 6.8-72 Gupta, S. P., Gupta, M. K. and Arya, A. S., **Seismic analysis of a complex industrial structure including soil structure interaction effect**, *Proceedings of First Caribbean Conference on Earthquake Engineering*, 280–289. (For a full bibliographic citation, see Abstract No. 1.2-21.)

A multistoried industrial structure with complex frames has been studied. Included in the analysis is the effect of soil-structure interaction. The soil flexibility has been repesented by two elastic springs, one translational and the other rotational, to account for the allowable displacements at the base of the structure. Results obtained have been compared with the case when the structure is treated as fixed. The effect of the change in the foundation soil condition on the dynamic response of this complex structure is also studied.

● 6.8-73 Iwashita, T. and Sakai, N., **Mechanical properties of plane frames with shear walls considering up-lift of footings—on the analysis of the frame with shear walls and slabs, Part 2** (in Japanese), *Transactions of the Architectural Institute of Japan, 286*, Dec. 1979, 55–63.

The column footings of frames with shear walls subjected to an incremental lateral load often uplift from the underlying soil because of the concentration of the load on the walls. This paper examines the properties of frames with shear walls, considering uplift of the column footings and the elastoplastic behavior of the members and soils. The soil under an individual footing is assumed to be a horizontal spring (K_H) and a vertical spring (K_V) which cannot resist tension. The analytical technique used is based on the method of displacement proposed in part 1 for a stiffness matrix analysis. The results of the analyses are summarized as follows. The stiffer the underlying soil, the more easily the column footing of the shear wall uplifts, which causes considerable deterioration in the horizontal strength of the frames. The yield of the beams occurs

● *See **Preface**, page v, for availability of publications marked with dot.*

earlier than the uplift for a small K_V, but for a large K_V, uplift occurs earlier than the yield. The maximum strength of the frame is about the same value regardless of the stiffness of the soil. The lateral load-bearing capacity of shear walls for lower stories does not deteriorate in the same manner, notwithstanding the uplift of the footing of the walls, which is greatly influenced by the strength of the soil and by beams having one end bounded by walls. When a frame reaches its maximum strength, the lateral load-bearing capacity of a shear wall with an uplifted footing is about the same value as for any size K_V.

● 6.8-74 Barata, F. E. et al., **Foundations under pulling loads in residual soil–analysis and application of the results of load tests,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 165–176. (For a full bibliographic citation, see Abstract No. 1.2–22.)

● 6.8-75 Bhandari, R. K. M., **Performance of cylindrical oil tanks founded in a seismic area on soil treated by compaction piles,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 19–34. (For a full bibliographic citation, see Abstract No. 1.2–22.)

The susceptibility of a refinery site to liquefaction was a major factor for which the foundations of the refinery storage tanks needed special attention. To counter liquefaction, the relative density of the loose to medium sands in the area was improved to eighty percent by compaction piles. In view of the enormity of the job as well as the high water table conditions at the site, the direct measurement of relative density was difficult and therefore the densification criteria were stated in terms of the SPT N values. The pattern and spacing of the compaction piles to satisfy the densification criteria are discussed. Settlements recorded during hydrotesting of the tanks are discussed in relation to the computed settlements. Satisfactory performance of the tanks as judged from the observed low peripheral distortional settlements is predicted.

● 6.8-76 Sams, C. E. and Browning, M. Y., **Analysis of vibratory behavior of machine foundations and finite element analysis for vibrations of surrounding ground,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 81–92. (For a full bibliographic citation, see Abstract No. 1.2–22.)

An analytical case study of the vibratory performance of soil-supported compressor foundations installed inside an existing building is presented. The foundation block was designed using semiinfinite elastic half-space theory to predict its performance. Near the end of the design process it was recognized that the design might not perform according to the calculations because of layered soil conditions at the site. Of particular concern was the fact that several of these vibratory machines would be located inside the building, with the potential for interacting with each other and for setting up vibrations in the building. Using a parametric study based on a variation of the dynamic elastic properties of the soils, finite element analyses were performed to predict vibrations in the surrounding ground. Vibrations of the machine foundations and transmitted vibrations on the surrounding floor, measured after the machines were installed, compare reasonably well with the range of vibrations judged possible from halfspace theory and finite element calculations.

● 6.8-77 Rogerio, P. R. and Ricco, M. F., **Horizontal loaded piers at the Sao Paulo city porous clay** (Carregamento lateral em tubuloes na argila porosa de Sao Paulo, in Portuguese), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 299–306. (For a full bibliographic citation, see Abstract No. 1.2–22.)

This paper presents the results of tests of piers subjected to a maximum lateral load of 34 tons. Horizontal displacements were measured by strain gages and inclinometers. In-situ tests were performed to determine the geotechnical characteristics of the site. The observed horizontal displacements permitted an analysis of the coefficient of horizontal subgrade reaction.

6.8-78 Lapin, S. K., **Experimental determination of inertial mass ratio of soil for vertical oscillations of foundations** (Eksperimental'noe opredelenie koeffitsienta prisoedinennoi massy grunta dlya vertikal'nykh kolebanii fundamentov, in Russian), *Osnovaniya, fundamenty i mekhanika gruntov, 3,* May 1979, 9–10.

Results determined from the processing of amplitude-frequency response curves plotted during tests of 17 foundations on 9 construction sites are presented. Inertial mass ratios of soils obtained on the basis of tests of 21 foundations resting on natural soil foundations are also presented. The dependence of the empirical values of the inertial mass ratios of the soils on dimensionless ratios is plotted. Data from the processing of amplitude-frequency response characteristics were verified with data from full-scale experiments confirming the dependences obtained earlier. A need to take into account the inertia of natural foundation soils in calculating the vertical oscillations of foundations is inferred.

● 6.8-79 Leshchinsky, D., Frydman, S. and Baker, R., **Study of soil structure interaction using finite elements and centrifugal models,** *Faculty Publication 259,* Faculty of Civil Engineering, Technion-Israel Inst. of Technology, Haifa, Sept. 1979, 41.

A comparison is presented of the results of centrifugal model tests and finite element analyses for the problem of load transfer to a rigid tie beam buried in sand. The finite element program utilized a nonlinear elastic (hyperbolic) soil constitutive relation obtained from tests in simple shear. It was found that, for this particular type of problem, the finite element solution may reasonably represent the interaction between the beam and the surrounding soil. It is pointed out that this agreement does not ensure that the use of such finite element analyses would be justified in problems involving rotation of principal directions and local unloading. The effect of compaction of the fill was investigated, and it was found that compaction leads to an increase in load transferred to the beam greater than that caused by density effects alone.

● **6.8-80** Price, G., **Field tests on vertical piles under static and cyclic horizontal loading in overconsolidated clay,** *Behavior of Deep Foundations,* 464–483. (For a full bibliographic citation, see Abstract No. 1.2–23.)

This paper describes experiments that provided information on the behavior of vertical tubular steel piles under horizontal working loads in London clay. Four aspects of piled foundation behavior were examined: (1) The effect of static and cyclic horizontal working loads on the behavior of a single pile. (2) The magnitude of the induced movements in unloaded piles at three- and six-pile-diameter spacings from a horizontally or vertically loaded pile. (3) The stiffness of a single pile loaded horizontally compared with the stiffness of a row of three piles loaded horizontally at right angles to the row. (4) The effect of a cap on the behavior of a row of three piles loaded vertically and horizontally (at right angles to the row). The main conclusions drawn are (1) Low levels of cyclic horizontal loading cause small adverse changes in the behavior of vertical piles. (2) The interaction between piles under horizontal load is considerably less than under vertical load. (3) Conclusion 2 is substantiated by the observations that the stiffness of three piles in a row is approximately three times the stiffness of a single pile under horizontal loads. (4) A cap significantly reduces the horizontal movements under load but has little effect on the vertical behavior of the piles. (5) The experimental techniques used enabled small changes in the pile-soil behavior to be successfully monitored.

● **6.8-81** Wang, M. C., Wu, A. H. and Scheessele, D. J., **Stress and deformation in single piles due to lateral movement of surrounding soils,** *Behavior of Deep Foundations,* 578–591. (For a full bibliographic citation, see Abstract No. 1.2–23.)

This paper presents a case history of structural damage to piles caused by lateral soil movement and an analysis of stress and deformation in the piles. The project involved cast-in-place concrete piles cased in steel pipes having a 40.6-cm (16-in.) outside diameter and a 38.7-cm (15 1/4-in.) inside diameter. The piles extended through a 7.6-m (25-ft) oyster shell fill and a 17-m (55-ft) soft clay layer and penetrated 7.6 m (25 ft) into a compact sand stratum. Because of overloading at the top of the fill, the soil surrounding the piles underwent lateral movement and caused cracking in the pile caps. The amount of lateral soil movement was measured using inclinometers. Based upon the measured soil deformation, lateral soil pressures were determined with the appropriate moduli of subgrade reaction. The soil pressures were used as lateral loads on a single pile. Using a finite element computer program that was developed based upon the theory of a beam on an elastic foundation, the deformation of the single pile and the horizontal reaction and resisting moment mobilized in the pile cap were analyzed. By comparing the horizontal reaction and resisting moment with the structurally determined ultimate values, the results of the pile behavior analysis were verified.

● **6.8-82** Robinson, K. E., **Horizontal subgrade reaction estimated from lateral loading tests on timber piles,** *Behavior of Deep Foundations,* 520–536. (For a full bibliographic citation, see Abstract No. 1.2–23.)

Lateral loading tests on timber piles in a variety of soil conditions are reported. Measured horizontal deflections and slopes of the piles are compared with predicted movements based on elastic theories and published values of horizontal subgrade reaction. It was found that the actual deflections and slopes of the piles were consistently less than the computed values, particularly for noncohesive soils. Based on the test results presented in this paper, suggested relationships between horizontal subgrade reaction and soil consistency are given. The horizontal subgrade reaction is a function of the magnitude and position of load application (it decreases with increasing soil stress). For noncohesive soils, increases in soil density caused by driving displacement piles apparently increase the horizontal subgrade reaction.

● **6.8-83** Parnes, R. and Weidlinger, P., **Dynamic response of an embedded pipe subjected to periodically spaced longitudinal forces,** *Grant Report 13,* Weidlinger Assoc., Menlo Park, California, Aug. 1979, 30.

The dynamic response of pipe systems buried in soil is studied. The degree of interaction between the pipe and surrounding soil as well as the amount of damping is established for pipes subjected to incoherent motion. The model considered is represented by a pipe of diameter D subjected to time-harmonic longitudinal forces acting periodically at intervals L in alternating directions. Such a loading pattern corresponds to the incoherent component of earthquake excitation. The pipe and the soil are assumed to behave as linear isotropic elastic materials and the interaction between the surrounding soil and pipe is assumed to occur through a shear force mechanism acting at the pipe-soil interface. The response is found to be expressible in terms of nondimensional ratios of density, velocity of wave propagation, and the aspect ratio D/L of the pipe.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Results are presented in terms of dynamic amplification factors for various applied frequencies of the applied forces. Peak response and resonant frequencies are determined and regions where radiation damping occurs are established. By choosing the suitable values of the governing parameters judiciously, the response can be obtained for either a continuous pipe or for an infinite train of pipe segments, interconnected by elastic joints at intervals L.

● **6.8-84** Parnes, R., **Static analysis of an embedded pipe subjected to periodically spaced longitudinal forces,** *Grant Report 12,* Weidlinger Assocs., New York, Aug. 1979, 19. (NTIS Accession No. PB 80 105 273)

The dynamic response of buried pipelines to earthquakes is best expressed in terms of dynamic amplification factors, i.e., as the ratio of dynamic to static response. In this report, the required static response of pipes of diameter D subjected to periodic longitudinal forces at intervals L, acting in alternate directions, is obtained. Such a load pattern corresponds to the incoherent motion occurring in pipes as a result of earthquakes. The static displacements and interacting stresses of a pipe-soil system are established and are found to be dependent, for a given soil, on the ratio of stiffness of the soil and pipe as well as on the aspect ratio D/L. Numerical results are presented for a series of pipes governed by the above nondimensional parameters.

6.8-85 Kotsubo, S. and Takanishi, T., **Analysis of the lateral resistance of pile-groups,** *Transactions of the Japan Society of Civil Engineers,* **10**, Nov. 1979, 52–54. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 277,* Sept. 1978, 15–24.)

This paper suggests a theoretical procedure for analyzing the interaction between groups of piles subjected to lateral load and the surrounding soil layer. The closed-form solution, including the soil-foundation interaction, can be deduced by using this procedure, and the computational values of the interaction factor are shown for several cases.

● **6.8-86** Idriss, I. M., Chmn., Ad Hoc Group on Soil-Structure Interaction of the Committee on Nuclear Structures and Materials of the Structural Division of ASCE, **Analyses for soil-structure interaction effects for nuclear power plants,** American Society of Civil Engineers, New York, 1979, 155.

● **6.8-87** Wolf, J. P., **Dynamic stiffness and seismic input motion of a group of battered piles,** *Nuclear Engineering and Design,* **54**, 3, Nov. 1979, 325–335. (Presented at ASCE National Convention, Boston, April 2–6, 1979.)

The dynamic stiffness (impedance function) and the corresponding seismic input motion of a group of battered piles, which can be end-bearing and floating and situated in any desired configuration in a horizontally stratified soil, are determined. The soil and the piles consist of frequency-dependent viscoelastic material with hysteretic damping. The base mat can be rigid or flexible. Any seismic excitation for which the free-field motion can be calculated may be specified including body waves propagating at an arbitrary angle and generalized surface waves. The soil is discretized by toroidal finite elements in conjunction with a Fourier expansion in the circumferential direction. Radiation and hysteretic damping are taken into account. The dynamic-flexibility matrix of the soil is generated, superimposing the basic dynamic-flexibility coefficients calculated by applying sequentially a horizontal and a vertical force at all nodes located on the axis of symmetry. The influence of the soil which is subsequently replaced by the piles is taken into consideration. Pile-soil-pile interaction is accounted for in this method. The formulation can also be applied to embedded foundations and buried structures such as tunnels and piping systems.

● **6.8-88** URS/John A. Blume & Assocs., **Applications in soil-structure interaction, Volumes 1-3,** *EPRI NP-1091,* Electric Power Research Inst., Palo Alto, California, June 1979, 288.

The complex phenomenon of soil-structure interaction is assessed. Relationships between the characteristics of the earthquake ground motions, the local soil and geologic conditions, and the response of the structures to the ground motions are studied. Each of the three volumes of this report addresses a unique topic.

Volume 1 describes the use of the explicit finite-difference method to study linear elastic soil-structure interaction. A linear two-dimensional study (using STEALTH 2-D) of different conditions that influence the dynamic compliance and scattering properties of foundations is presented. The explicit finite-difference method can be used to analyze a complete ground-building system as well as to evaluate compliances and scattering coefficients, and can easily be extended to the three-dimensional case.

Volume 2 describes the use of the FLUSH computer code to compute the soil-structure interaction during SIMQUAKE 1B, an experimental underground blast excitation of a 1/12-scale model of a nuclear containment structure. Evaluation was performed using transient excitation, applied to a finite-difference grid. Dynamic foundation properties were studied to determine the influence of various parameters. Results indicate that the orientation and location of the source relative to the site and the wave environment at the site may be important parameters to be considered. Differences between the computed and experimental recorded responses are indicated, and reasons for the discrepancy are suggested.

● *See **Preface**, page v, for availability of publications marked with dot.*

Volume 3 presents a case study that examined structural and ground response data tabulated and cataloged from tests at the U.S. Dept. of Energy's Nevada Test Site for its applicability to the soil-structure interaction questions of interest. Description, methods, and evaluation of data on soil-structure interaction from forced vibration tests are presented. A two-dimensional finite-difference grid representing a relatively rigid structure resting on uniform ground was analyzed and monitored. Fourier spectra of monitored time histories were also evaluated and are presented. Results show clear evidence of soil-structure interaction and significant agreement with theory.

6.9 Fluid-Structure Interaction

● 6.9-1 Dong, R. G., **Size effect in damping caused by water submersion**, *Journal of the Structural Division, ASCE,* **105**, *ST5,* Proc. Paper 14581, May 1979, 847–857.

An important effect of water submersion on the dynamic response of a structure is the increase in effective damping. The dynamic response of submerged structures is of interest to the nuclear power industry for reasons of operational safety during seismic and other dynamic excitations. In this paper, the added damping contribution that results from the viscosity of water and the dependence of the contribution on structural size are examined. Other factors considered are the applicable range of viscous damping with respect to displacement amplitude and, as far as damping is concerned, how far must neighboring members be from each other to respond as if in open water. An expression is derived for relating the damping value to structural size. Estimated added-damping values for representative fuel elements, fuel bundles, and main steam-pressure-relief-valve lines that are based on the derived expression for added damping are given.

● 6.9-2 Aslam, M., Godden, W. G. and Scalise, D. T., **Earthquake sloshing in annular and cylindrical tanks**, *Journal of the Engineering Mechanics Division, ASCE,* **105**, *EM3,* Proc. Paper 14643, June 1979, 371–389.

The sloshing response of water in annular and in cylindrical tanks under horizontal earthquake ground motions is studied. A linear analysis, developed for the general annular tank problem, is based on potential flow theory. The predicted values of natural frequencies, surface displacements, and dynamic pressures are compared with measured data from shaking table tests. Experimental studies were conducted on 1/80th- and 1/15th-scale models of a 120-ft annular tank, and correlation data are presented for sinusoidal and simulated earthquake motions. Test results from the sloshing of water in a 12-ft-diam cylindrical tank show that the annular tank solution is also applicable in this case. The range of surface displacement within which linear theory gives satisfactory results was established experimentally.

● 6.9-3 Bathe, K. J. and Hahn, W. F., **On transient analysis of fluid-structure systems**, *Computers & Structures,* 10, *1/2,* Apr. 1979, 383–391. (For a full bibliographic citation, see Abstract No. 1.2-4.)

Finite element procedures for the dynamic analysis of fluid-structure systems are presented and evaluated. The fluid is assumed to be inviscid and compressible and is described using an updated Lagrangian formulation. Variable-number-nodes isoparametric two- and three-dimensional elements with lumped or consistent mass idealization are employed in the finite element discretization. The incremental dynamic equilibrium equations are solved using explicit or implicit time integration. The solution procedures are applied to the analysis of a number of fluid-structure problems including the nonlinear transient analysis of a pipe test.

● 6.9-4 Marchaj, T. J., **Importance of vertical acceleration in the design of liquid containing tanks**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 146–155.

This paper examines the elastic response of a fluid-filled tank subjected to vertical earthquake ground motions. Contemporary earthquake design techniques for such tanks do not consider vertical ground motions. An elastic fluid-filled system when excited vertically can be analyzed as a single degree-of-freedom system that vibrates (pulsates) radially against the vertical center axis of the tank without distortions of the tank cross section. The natural period of radial pulsation for metal tanks varies from 0.2 sec to 0.7 sec for tank diameters from 20 ft to 200 ft, respectively, at the maximum loading conditions when a tank is full. This range roughly corresponds to the maximum response spectra velocity or acceleration values for typical earthquakes. The vertical ground motions are translated into radial pulsations of a tank-fluid system and result in development of additional stresses in the wall in the circumferential direction. These additional stresses will be 12,400 psi at a horizontal acceleration of 0.3 g and 20,600 psi at 0.5 g. For the latter case, the stresses already existing in the wall as a result of the static liquid load will be doubled. A detailed analysis of the tank deformations and combined stresses in the wall at the base clearly explains the occurrences of the so-called elephant-foot phenomenon. The lack of consideration of the vertical acceleration in design procedures creates a situation in which all tanks already built are underdesigned and could fail during an earthquake with a horizontal acceleration greater than 0.3 g. Suggestions are given to improve the design of existing tanks.

● 6.9-5 Lee, S. C. and Reddy, D. V., **Seismic response of elevated liquid storage tanks**, *Proceedings of the 2nd U.S.*

● *See* ***Preface****, page v, for availability of publications marked with dot.*

National Conference on Earthquake Engineering, Earthquake Engineering Research Inst., Berkeley, California, 1979, 193–202.

The need for predicting the response of large liquid storage tower structures, incorporating detailed shell behavior of the tanks, has prompted the studies described in this paper. The work, an extension of the work by Balendra and Nash on the seismic response analysis of ground-supported liquid storage tanks, is restricted to the formulation of a procedure for seismic analysis of axisymmetric water towers.

● 6.9-6 Tung, C. C., **Hydrodynamic forces on submerged vertical circular cylindrical tanks under ground excitation,** *Applied Ocean Research,* **1,** 2, Apr. 1979, 75–78.

This paper investigates hydrodynamic pressures and forces on submerged vertical cylindrical tanks under the action of harmonic ground excitations. Water is assumed to be incompressible and inviscid, motion irrotational, and waves of small amplitude. A semi-analytical method is used for the solution, that is, the fluid domain is divided into inner and outer regions. The Laplace equations governing velocity potentials for the two regions are solved by the separation of variables and are expressed in terms of eigenfunctions of the resulting equations which satisfy appropriate boundary conditions. Continuity of pressure and velocity at the interface of the inner and outer regions provides the necessary equations from which the velocity potentials, pressures, and forces are obtained. Numerical results are presented in graphical form for forces and pressures at a range of excitation frequencies for selected proportions of tank geometry and water depth.

● 6.9-7 Vandiver, J. K. and Mitome, S., **Effect of liquid storage tanks on the dynamic response of offshore platforms,** *Applied Ocean Research,* **1,** 2, Apr. 1979, 67–74.

The sloshing of liquids in storage tanks on fixed offshore structures affects both the natural frequencies and damping. Analytical procedures by which one may account for these effects are presented. Also shown is a method for the design of tankage that will result in the suppression of the dynamic response at the fundamental flexural natural frequency of the structure. An important aspect is that no new equipment is required but only the optimum configuration of tankage that is already required for storage of water, fuel, mud, or crude oil. Supporting data from full-scale field studies are presented.

● 6.9-8 Mei, C. C., Foda, M. A. and Tong, P., **Exact and hybrid-element solutions for the vibration of a thin elastic structure seated on the sea floor,** *Applied Ocean Research,* **1,** 2, Apr. 1979, 79–88.

Exact analytical solutions are derived for simple elastic structures vibrating in water. Linear acoustic and beam theories are used to treat several cases, some of which have already been studied by more approximate methods. A hybrid element method based on a localized variational principle is demonstrated numerically for a beam-dam; its theoretical basis is then generalized for an arbitrary two-dimensional elastic structure. Foundation compliance is not included.

● 6.9-9 Kar, A. K., **Structural overturning and buoyancy,** *Proceedings, The Institution of Civil Engineers,* Part 2, **67,** Paper 8214, June 1979, 475–482.

Structures should be safe from the adverse effects of natural phenomena such as wind, earthquake, lateral pressure, and buoyancy. One criterion of safety is stability against overturning, with the dead weight providing the stabilizing force. Wind, earthquake, lateral pressure and so on are destabilizing forces. The common civil engineering practice is to deduct the effects of buoyancy from the righting moments. For the conventional rigid structure, the rigid subgrade model, it is shown by physical considerations and mathematical modeling that buoyancy is not effective in causing overturning as a primary mode of failure. This contrasts with the current practice of considering buoyancy as a destabilizing force. Correction of this misconception would lead to considerable savings in construction.

● 6.9-10 Akkas, N., Akay, H. U. and Yilmaz, C., **Applicability of general-purpose finite element programs in solid-fluid interaction problems,** *Computers & Structures,* **10,** 5, Oct. 1979, 773–783.

The elasticity matrix of a general purpose finite element program, SAP IV, is modified in such a way that it becomes possible to idealize water as a structural finite element with zero shear modulus. Using the modified version of SAP IV, several solid-fluid interaction problems are solved. The numerical solutions are compared with the available analytical solutions. They are shown to be in reasonable agreement. Also, by solving an exterior shell-fluid interaction problem, the pressure wave propagation in the acoustic medium is presented. The uses of both the direct-integration and the mode-superposition options of the program are investigated for the time-integration of the interaction problems.

● 6.9-11 Minowa, C., **Dynamic analyses for rectangular water tanks** (in Japanese), *Transactions of the Architectural Institute of Japan,* **285,** Nov. 1979, 23–32.

This paper describes theoretical and experimental studies concerning rectangular water storage tanks. In the theoretical study, Kito's method is employed. Bending displacements of the walls perpendicular to an excitational direction (which are called the pressured walls), shear

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

displacements of the walls parallel to this direction (which are called the side walls), and displacement of the base frame are assumed. The water in the tank is regarded to have a velocity potential that satisfies the condition of a free surface, the continual conditions of velocities on the pressured walls, and the three-dimensional Laplace equation. From these assumptions, the kinematic energies and the potential energies can be obtained. The vibrational equations of this system can be expressed by substituting these energies into the Euler equation. This analysis is concluded by the solving of the multidegree vibrational equations. The dynamic tests were conducted on a water storage tank made with steel panels with dimensions of 1 m x 1 m. This rectangular tank has a capacity of 48 t (width x length x height = 3 m x 4 m x 4 m). The large-scale shaking table at the National Research Center for Disaster Prevention in Tsukuba Newtown was used in this experiment. The frequencies and the hydrodynamic pressures were measured. The mathematical simulation for this experiment was carried out in the frequency and the time domains. The results of theoretical analyses for this tank are in partial agreement with the experimental results.

● 6.9-12 Kana, D. D., **Liquid slosh response in a horizontal cylindrical tank under seismic excitation**, Southwest Research Inst., San Antonio, Texas, Nov. 1979, 41.

Previous research efforts have shown that the dynamic sloshing response of partially filled liquid tanks with circular vertical cross sections tends to display significant nonlinearity with increasing amplitude. Furthermore, some tanks are geometrically asymmetrical so that the direction of horizontal excitation is a significant factor. In order to study these effects in a tank of practical geometry, a series of experiments was performed to measure seismic sloshing response in a horizontal cylinder, partially filled with water. The tank was designed to be a 1/16-scale model of similar tanks used in a number of current nuclear plant installations. Most of the experiments were conducted for three different liquid depths, and for transverse, longitudinal, and combined horizontal excitation directions.

Liquid wave height and pressure transfer functions were measured initially at several tank locations under steady-state harmonic excitation. Plots of response versus excitation amplitude showed significant nonlinearity (either curved upward or downward) with increasing response amplitude for the most dominant first sloshing mode. However, the resonance frequency for a given mode appeared to be independent of excitation amplitude. At the same time, modal damping also varied significantly with amplitude. A similar series of observations were made for transient harmonic tests in which peak wave response was measured for different numbers of input harmonic cycles at a given natural frequency.

An analog computer representation of the dominant first transverse sloshing mode was developed which included a linear plus cubic velocity damping term and amplitude saturation. It was found that this form of nonlinearity could be utilized to duplicate any of the steady-state or transient harmonic tests. Furthermore, results also matched those determined from quasilinear transfer function theory when the appropriate average slope of the curved steady-state response characteristics was used in the linear prediction equations.

A series of simulated earthquake runs was performed, and data were acquired to demonstrate variation of peak responses with horizontal excitation displacement. Quasilinear transfer function theory, along with that from available linear analytical models, was used to predict results of the simulated seismic runs. Predicted and measured results appeared to compare quite well providing that average transfer functions were used in the prediction equations.

Final results demonstrate that use of an equivalent rectangular tank analytical model for prediction of responses can be significantly in error, and must be applied with care. A method is developed whereby this theory can be modified to provide more accurate predictions by use of empirically determined transfer functions. It is further found that time-averaged RMS displacement amplitude is a very useful parameter for correlation with peak sloshing responses. The physical mechanism which generates the observed nonlinear amplitude and damping behavior remains to be determined, even though its mathematical form was identified.

● 6.9-13 Hori, N., Tani, S. and Tanaka, Y., **Dynamic analysis of cylindrical shells containing liquid** (in Japanese), *Transactions of the Architectural Institute of Japan*, 282, Aug. 1979, 83–94.

It is the purpose of this report to formulate and solve theoretically the forced motion problems of cantilevered circular cylindrical shells partially filled with liquid and subjected to horizontal earthquake excitations. Thin cylindrical shells are considered and the internal liquid is assumed to be an ideal liquid. The fundamental equations are obtained based on the Donnell approximation, the linear elastic shell theory with small deflection, and the linear potential flow theory. The unit mode displacement is obtained by approximating displacement for the axial direction as a series of displacement functions for a cantilevered beam and by applying the Rayleigh-Ritz method. Assuming that the pressure of the internal liquid is divided into convective pressure and impulsive pressure, the impulsive pressure is represented as the sum of pressures induced by the rigid motion and the elastic deformation of the shell. Since the frequencies of the first few dominant modes of liquid sloshing are usually much smaller than the frequency

● *See **Preface**, page v, for availability of publications marked with dot.*

of a liquid-shell system, the effect of the elastic deformation of the shell on the convective pressure is neglected. Numerical computations proved that the response pressure when the elastic deformation of the shell is considered is larger than the pressure when only the rigid motion of the shell is considered.

● 6.9-14 Young, F. M. and Hunter, S. E., **Hydraulic transients in liquid-filled pipelines during earthquakes,** *Lifeline Earthquake Engineering–Buried Pipelines, Seismic Risk, and Instrumentation,* 143–151. (For a full bibliographic citation, see Abstract No. 1.2–16.)

The relatively low peak accelerations associated with earthquakes might erroneously suggest that hydraulic transients in liquid-filled pipelines are not significant in comparison to the factors of safety usually employed. This paper demonstrates through a one-dimensional method of characteristics analysis that velocity amplifications (and resulting transient pressures) of about ten at the hydraulic resonance and from three to six for ground motion frequencies in excess of the resonance are possible. Since the hydraulic resonance for many parts of a large pipeline system would be within the frequency spectrum encountered for earthquake motion, the estimate of peak overpressure given by Okamoto may be low by a factor of ten.

For a practical system, such as a city water supply, the implications are different. The low system pressure would cause the system to experience pressures below the vapor pressure and, hence, column separation would be expected. Collapse of this vapor pocket between the separated columns might be expected to produce overpressure in excess of that necessary to damage system components and/or piping.

● 6.9-15 Fischer, D. F., **Explicit evaluation of the apparent fluid mass at the vibration of fluid filled cylindrical tanks,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/8, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

The velocity potential for a compressible fluid is found by use of Galerkin's method. Free surface displacements and a flexible tank wall are assumed. Explicit expressions for the impulsive mass, the impulsive moment, and the overturning moment are derived for wave number $m = 1$. In case of $m \geq 1$, the dynamic effect of the fluid is represented by a fictitious apparent mass in explicit form. Comparisons with measurements and a parametric earthquake study are given.

● 6.9-16 Chu, M., Lestingi, J. F. and Brown, S. J., **Experimental seismic test of fluid coupled co-axial cylinders,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/9, 9. (For a full bibliographic citation, see Abstract No. 1.2–20.)

This paper considers the experimental seismic time history and RMS response of a series of fluid-filled (H_2O) co-axial thin cylinders. The influence of gap and viscous damping effects are also considered. Three different combinations of acrylic cylinders are used, i.e., one outside cylinder and three inside cylinders with different inside diameters. The cylinders have the same thickness (0.235 in.) and length (24 in.), which when paired with the outer cylinder provided annular gap sizes of 0.9375 in., 0.4375 in. and 0.125 in., respectively. The outside cylinder is point excited and the natural frequencies, mode shapes, and damping ratios are determined using two mapping eddy current probes, one each for the inner and outer cylinder, respectively. The damping ratio at a given natural frequency is obtained using the half-power technique. For the seismic test, the three co-axial setups are mounted on a rigid steel support frame. The support frame is suspended from the ceiling by flexible rods. The suspended test frames are excited by a hydraulic shaker with a simulated seismic input (3-43 Hz). The time history response of both inner and outer cylinders are monitored by both eddy current probes (displacement) and mini-accelerometers (acceleration). Wave form and spectral density plots are then made.

Three distinct responses are observed: one is a beam mode of the inner cantilevered cylinder and the other two are in-phase or out-of-phase breathing modes between the inner and outer cylinders ("in-phase" and "out-of-phase" refer to circumferential modes of vibration). The out-of-phase modes approach zero or some limiting value as the gap size decreases, while the in-phase modes have increasing frequency as the gap becomes smaller. It is shown that damping ratios increase from about 5% to about 15% as the gap decreases, while damping ratios for the in-phase response remain within the 4-5% region as the gap size becomes smaller. Comparison between the inner and outer cylinder displacement responses resulting from the seismic loadings shows the ratios of the averaged peak responses varies as a function of the gap between the inner and outer cylinder. Similar trends were observed on the spectral densities of the responses. It also is shown that the gap size has a strong influence in either increasing or decreasing the frequency response and/or the damping ratios of the system.

● 6.9-17 Arockiasamy, M., Babu, P. V. T. and Reddy, D. V., **Probabilistic seismic fluid-structure interaction of floating nuclear plants platforms,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 4/7, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

This paper describes the calculations of the probabilistic seismic responses of a floating nuclear plant (FNP) platform restrained by mooring struts attached to caissons and located within a protective breakwater. An offshore nuclear power plant, similar to the one proposed for the Atlantic Generating Station, is chosen as the example problem. The FNP is modelled using eight-noded isoparametric plane strain elements. The buoyancy effects are accounted for by boundary elements with appropriate axial stiffnesses. The fluid medium is isolated from the structure, and discretized using two-dimensional plane strain eight-noded isoparametric quadrilateral finite elements with pressures as the nodal unknowns. The fluid-structure interaction is simulated by incorporating the hydrodynamic forces, associated with frequency-dependent added mass and damping, as external loading at the interfacial nodes of the FNP platform. The input data values of the ground motion are transformed into complex amplitudes using the Cooley-Tukey Fast Fourier Transform, the external load vector is computed, and the frequency response of the fluid-structure system determined. The displacement in the time domain is obtained using the inverse transform, and the mean square value of the platform response computed as the area under the spectral density-frequency curve over the frequency range of interest. The work is being extended to the application of extreme value statistics for obtaining the peak responses, based on a number of excitation inputs with the same duration.

● 6.9-18 Pramila, A., **A simple but efficient FEM-version for pipe vibration and instability,** *International Conference on Computer Applications in Civil Engineering, October 23–25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-77–82.

The paper suggests a new finite element model for pipe vibration and stability analysis. The model consists of rigid elements connected with each other by linear moment springs. Example problems studied using this model show its efficiency. The paper also contains a brief comment on the previous erroneous use of Hamilton's principle in pipe vibration problems.

● 6.9-19 Bedrosian, B., Ettouney, M. and Brennan, J., **Dynamic pressures in annulus-shaped pressure suppression pools of boiling water reactors generated by earthquake ground motions,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/11, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Pressure-suppression pools of annular-circular geometry are used in containments for boiling water reactor (BWR) plants of Mark II and Mark III configurations and must be designed to withstand earthquake effects. Analytical solutions are obtained for dynamic pressures and free-surface displacements (sloshing) induced in annular-circular water pools with horizontal or flat bottoms when subjected to earthquake ground motions. Water is modeled as an inviscid, compressible fluid and sloshing is accounted for. The pool boundaries are assumed to be rigid. Analytical solutions are obtained in the frequency domain as Fourier-Bessel or Fourier-modified Bessel functions depending upon the magnitude of the exciting frequency and the compressibility of water. To obtain the effects that flexible pool boundaries have on induced hydrodynamic pressures and sloshing, a two-step analysis is implemented. In the first step, the solution described above is used to obtain a set of frequency-dependent hydrodynamic (added) masses. In the second step, the structure with the previously computed hydrodynamic masses added at discrete locations on the fluid-structure interface is analyzed for an earthquake excitation using the finite element method. Structural accelerations are obtained in the frequency domain. With known pool boundary accelerations, dynamic pressures induced in the fluid are then obtained. Analytical results are compared with the results of experiments performed elsewhere. It was found that the flexibility of the structure studied affects the hydrodynamic pressures induced in the pool.

● 6.9-20 Clough, R. W., Niwa, A. and Clough, D. P., **Experimental seismic study of cylindrical tanks,** *Journal of the Structural Division, ASCE,* **105,** *ST12,* Proc. Paper 15062, Dec. 1979, 2565–2590.

The earthquake response behavior of ground-supported, thin-shell, cylindrical liquid storage tanks was studied experimentally by means of the Univ. of California at Berkeley shaking table. The models, which were 12 ft x 6 ft and 7 3/4 ft x 15 ft, were fabricated from sheet aluminum to represent steel tanks three times larger and subjected to simulated earthquake accelerations with intensities up to 0.5 g. Principal test parameters included base fixity (fixed or free to uplift) and top condition (open, fixed, or floating roof). The most significant observation was that out-of-round distortions were induced in both fixed and free-base tanks in addition to the expected lateral deflection point. Stresses and deflections associated with the out-of-round response were not negligible. Also, the uplift behavior of unanchored tanks differed greatly from design prediction, with observed stresses several times larger than expected. The models performed satisfactorily despite the unexpected behavior characteristics.

● 6.9-21 Fischer, D., **Dynamic fluid effects in liquid-filled flexible cylindrical tanks,** *Earthquake Engineering & Structural Dynamics,* 7, 6, Nov.–Dec. 1979, 587–601.

The velocity potential of a compressible fluid is found by means of Galerkin's method. Free surface displacements and a flexible tank wall are assumed. Explicit expressions for the impulsive mass, the impulsive moment, and the overturning moment are derived for wave number $m = 1$.

In the case of $m \geq 1$, the dynamic effect of the fluid is represented by a fictitious apparent mass in explicit form.

6.9-22 Kotsubo, S. and Takanishi, T., **Analysis of hydrodynamic pressure on multi-piles foundation during earthquakes,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 44–45. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 276,* Aug. 1978, 1–12.)

This paper presents a theoretical procedure for analyzing the hydrodynamic pressure on multi-pile foundation. The closed-form solution, including two- and three-dimensional hydrodynamic pressure on multi-pile foundation (for both the cases of rigid and flexible vibration of piles) can be deduced by using this procedure. Experiments using a number of two-dimensional models are carried out and the theoretical values are compared with the experimental values.

● 6.9-23 Kana, D. D., **Seismic response of flexible cylindrical liquid storage tanks,** *Nuclear Engineering and Design,* **52,** *1,* Mar. 1979, 185–199.

Liquid slosh and tank wall flexural vibrations are studied in a flexible model storage tank subject to simulated earthquake environments. Emphasis is placed on determining the influence of wall flexural vibrations on induced stresses. The approach is basically experimental. Similitude considerations are presented, a series of scale model experiments discussed, and preliminary observations evaluated. These evaluations permit the formulation of an approximate analytical model for prediction of seismically induced stress. The range of validity for this model is established by comparison of predicted responses with observed results.

● 6.9-24 Rush, R. H. and Jackson, J. E., **Treatment of hydrodynamic effects for toroidal containment vessels,** *Nuclear Engineering and Design,* 53, 2, July 1979, 217–222.

Hydrodynamic effects in liquid-shell systems may be characterized in terms of structural degrees-of-freedom alone if an ideal fluid is assumed. The hydrodynamic effects are modeled by means of a consistent (full) added mass matrix which is obtained via finite element methods. The procedure is demonstrated for the case of a nuclear reactor toroidal containment vessel partially filled with water. Results demonstrate the superiority of this method over diagonal added mass procedures, such as the tributary area method.

6.10 Vibration Measurements on Full Scale Structures

● 6.10-1 Housner, G. W. and Haroun, M. A., **Vibration tests of full-scale liquid storage tanks,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 137–145.

Theoretical and experimental investigations of the dynamic behavior of cylindrical liquid storage tanks were conducted to seek possible improvements in the design of such tanks to resist earthquakes. This paper records the principal results obtained during the second phase of the study which was concerned with vibration tests of full-scale tanks. Three water storage tanks, with different types of foundations, were tested to assess the influence of support conditions. Ambient and forced vibration tests were carried out to determine the natural frequencies and, if possible, the mode shapes of vibrations. Significant higher order circumferential modes and rocking motions were clearly observed. Comparison with previously computed frequencies and mode shapes shows good agreement with the experimental results.

● 6.10-2 Stephen, R. M. and Wilson, E. L., **Dynamic behavior of a pedestal base multistory building,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1076–1084.

The dynamic properties of the translational modes in the N-S and E-W directions, as well as the torsional modes of the Rainier Tower building in Seattle, Washington, were determined by full-scale dynamic tests. The resonant frequencies from both studies are in very good agreement in all separated modes of vibration, with the maximum difference being about 6%. The ratios of the observed higher mode frequencies with respect to the fundamental frequency from both dynamic studies of the building indicate that the overall structural response is predominantly of the shear type. Comparison of the forced and ambient vibration experiments demonstrates that it is possible to determine the natural frequencies and mode shapes of typical modern buildings using the ambient vibration method. There were difficulties in the evaluation of equivalent viscous damping factors from ambient vibration studies and it is more realistic to expect assessment of the range of damping factors from this type of study, rather than damping values associated with each mode of vibration. A comparison of the translational analytical results shows good agreement with the experimental study when the flexibility of the base is considered. The maximum differences range from about 1% at the first mode to about 6% at the higher modes. Even with the fixed-base analytical model, the differences are only about 8%. It would appear

● *See **Preface,** page v, for availability of publications marked with dot.*

from the first translational mode shape that the actual building is slightly more flexible than the analysis indicates. In comparing the torsional analytical results for a fixed-base model with the experimental results, the actual building indicates a stiffer structure.

6.10-3 Rainer, J. H. and Pernica, G., **Dynamic testing of a modern concrete bridge,** *Canadian Journal of Civil Engineering,* **6,** *3,* Sept. 1979, 447–455.

A post-tensioned reinforced concrete bridge, slated for demolition, was tested to obtain its dynamic properties. The 10-yr-old bridge consisted of a continuous flat slab deck of variable thickness having a total width of 103 ft (31.39 m) and spans of 28 ft 6 in. (8.69 m), 71 ft (21.64 m), and 42 ft 6 in. (12.95 m). The entire bridge was skewed 10°50′ and the deck was slightly curved in plan. The mode shapes, natural frequencies, and damping ratios for the lowest five natural modes of vibration were determined using sinusoidal forcing functions from an electrohydraulic shaker. These modes, located at 5.7, 6.4, 8.7, 12.0, and 17.4 Hz, were found to be highly dependent on the lateral properties of the bridge deck. Damping ratios were determined from the widths of resonance peaks. The modal properties from the steady state excitation were compared with those obtained from measurements of traffic-induced vibrations and good agreement was found between the two methods.

● **6.10-4** Shepherd, R., Brown, H. E. E. and Wood, J. H., **Dynamic investigations of the Mohaka River Bridge,** *Proceedings, The Institution of Civil Engineers,* Part 1, **66,** Paper 8206, Aug. 1979, 457–469.

The Mohaka River Bridge in the North Island of New Zealand is a three-span, steel-truss bridge. Movements under ambient wind, steady-state forced vibration, and traffic excitation were recorded; and values of characteristic frequencies, mode shapes, damping properties, and impact factors were determined. Theoretical modal properties were calculated using two mathematical models and the predicted characteristics were compared with those established experimentally; acceptable correlation was noted. Although the response of the bridge to traffic may well be much more readily discernible than would be that of a typical concrete bridge of similar span, the amplitudes are not excessive and there need be no particular concern regarding the influence of vibrations on the main truss members.

● **6.10-5** Ruhl, J. A. and Berdahl, R. M., **Forced vibration tests of a deepwater platform,** *Proceedings of Eleventh Annual Offshore Technolgy Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. II, OTC 3514, 1979, 1341–1354.

Forced vibration tests were conducted on a deepwater platform using two 3000-lb masses driven by an electrohydraulic control system. The fundamental and second group of end-on, broadside, and torsion modes were positively identified and excited to levels well above ambient, using steady-state tests so that damping could be computed from free-vibration decay records. Modal damping values were found to be less than two percent of critical in the fundamental group of modes and in the three-to-five-percent range for the second group of modes. Random forced vibration tests were also conducted, and the quadrature component of the cross spectrum between the input random force and the response was found to identify the natural modes and filter out the machinery-induced vibration.

● **6.10-6** Jehlicka, P., Malcher, L. and Steinhilber, H., **Low level earthquake testing of the HDR: comparisons of calculations and measurements for mechanical equipment** (Erdbebenuntersuchungen an der HDR-Anlage bei niederer Anregung; Vergleich Messung-Rechnung fur maschinentechnische Anlagen, in German), *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/3, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Natural and forced vibratory behavior of the reactor pressure vessel (RPV) and two piping systems of the decommissioned nuclear power plant HDR, Kahl were determined using shaker, snapback, and explosive excitation. Shakers were applied within the building and directly attached to the equipment. Explosive excitation was provided by buried charges to 10 kg placed 10 to 25 m from the building. Peak accelerations up to 0.6 m/sec^2 and strains to 10^{-4} were measured at the pipes. Separate investigations to determine the vibratory behavior of the RPV and two piping systems were performed without knowledge of the test results by several sources, using different structural models and various programming and calculational systems. Different types of boundary conditions and coupling between pipes, RPV, and other heavy components were investigated.

The calculations of the basic harmonics of the recirculation loop agree well with each other. However, the experimentally measured values were of too low a level to allow a meaningful comparison. The excitation levels were insufficient to overcome the highly preloaded springs and the frictional loads of the constant force hangers upon which it was supported. The comparison of measured natural harmonics in the saturated steam piping system with calculations showed that better results were produced using simple uncoupled models than with those in which the primary components were coupled. In the program used, the supports in the model boundaries were simulated with strong spring elements rather than rigid ones. The results of shaker testing on the recirculation loop and the

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

RPV showed in part much lower amplitude response than the calculations would have predicted. This was however expected from previous eigenvalue comparisons and is attributable to the large restraints on the structure. This effect was however not observed in the explosive testing where primary excitation came from the building itself. In this case, measured and THMA calculated values of the time history of the natural oscillation agreed reasonably well. This was also the case for calculations of the saturated steam piping system under explosive excitation.

● **6.10-7** Jehlicka, P., Malcher, L. and Steinhilber, H., **Low level earthquake testing of the HDR: comparisons of calculations and measurements for the reactor building** (Erdbebenuntersuchungen an der HDR-Anlage bei niederer Anregung; Vergleich Messung-Rechnung f.d. Reaktorgebaude, in German), *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/2, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Natural and forced vibratory behavior of the decommissioned nuclear power plant HDR, Kahl was determined using shaker and explosive excitation, which was provided by buried charges to 10 kg placed 10 to 25 m from the building. Analytical investigations to determine the vibratory behavior of the building were performed without knowledge of the test results by several sources, using different building and soil models and various programming and calculational systems.

The comparison of analytically and experimentally determined eigen-frequencies and mode shapes of the soil-dependent modes of rocking, vertical translation, and torsion showed that the models incorporating soil springs simulated the vibrational behavior better than the coupled finite element (FE) models. Moreover, the springs calculated using the halfspace theory could hardly be differentiated from those of the FE models despite very inhomogeneous soil properties at the site. The correct torsional spring was not estimated by either model.

The models used for the building were beam models (40 to 300 degrees-of-freedom) and shell models (1.000 to 10.000 dof). Comparing the measured and calculated results of the structural modes of the beam models indicated a basic systematic variation caused by coupling the inner and outer concrete structure rigidly in the vicinity of the foundation, over-estimating the frequency of the first out-of-phase bending mode. In one case using the more costly and time consuming FE model, an almost perfect agreement between measured and calculated results was obtained; whereas in two others, correlations were made only with difficulty. It appears that the ability to handle and apply a given model should not be underestimated in its effect on the eventual results.

Comparisons of the calculations showed that for the type of excitation considered the vibratory behavior of the building and corresponding loading of the plant equipment can be determined virtually as well with a beam model on soil springs as with a fine mesh FE model.

● **6.10-8** Mizuno, N. et al., **Forced vibration test of BWR type nuclear reactor buildings considering through soil coupling between adjacent buildings,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Forced vibration tests of two adjacent BWR-type reactor buildings were conducted on a large scale in 1977 at the Hamaoka Nuclear Power Station of the Chubu Electric Power Co., Inc., in Japan. The tests were conducted while building No. 1 was generating power and while building No. 2 was under construction. The experimental methods used are described. Resonance curves were analyzed with respect to natural frequency, viscous damping ratio, and the natural mode. An indication is given of the vibrational behavior of two reactor buildings when coupling occurred within the soil connecting the buildings.

● **6.10-9** Igarashi, T., Arai, K. and Fujita, K., **Field vibration test results and design for reactor coolant piping systems of ATR "FUGEN,"** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/7, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In most nuclear power plants in Japan, field vibration tests have been performed on piping systems to verify the appropriateness of the seismic design and the integrity of the pipework. For a prototype heavy-water reactor "Fugen" (a 165-MWe heavy-water-moderated, boiling light-water-cooled pressure tube reactor, developed as part of a national project in Japan), the reactor coolant piping systems are connected with the pressure tube, the steam drums, and the recirculation pumps. The steam drums are set in the top level and the recirculation pumps in the bottom level. This configuration makes it difficult to compare this type of reactor with reactors of other types. The seismic analysis of the main piping systems in the Fugen was performed by means of the modal analysis method using the floor response spectrum. The vibration tests of the main piping systems were carried out by using electromagnetic exciters placed in the plant after its construction. In these vibration tests, the dynamic characteristics (eigen-frequencies, damping factors, and mode shapes) were measured. These tests and analyses confirmed that the reactor coolant piping systems of the Fugen were designed and constructed safely and properly.

● **6.10-10** Pardoen, G. C., **Imperial County Services Building: ambient vibration test results,** *79-14,* Dept. of

Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Dec. 1979, 26.

A research effort is presently being devoted to an in-depth experimental and analytical study of the Imperial County Services Building in El Centro, California. The experimental component of the research project has been devoted to low-level structural excitations (ambient and forced vibration); however, the potential for strong-motion experimental results and the structure's inherent nonlinear behavior exist because the structure is in a highly seismic area and is instrumented under the California Strong Motion Instrumentation Program. On Oct. 15, 1979, this earthquake potential became a reality when a magnitude 6.4 earthquake caused extensive damage to the structure. The earthquake was centered on the Imperial Fault near the U.S.-Mexican border. The analytical component of the research project is being devoted to the development of a valid mathematical model to accurately represent the low-level forced vibration while investigating methods and techniques needed to represent the nonlinear structural behavior caused by the strong-motion records of 1934, 1940, and 1979. This report, one of several related to the Imperial County Services Building, is devoted to the presentation of the data resulting from the ambient vibration tests conducted during February and May 1979.

● **6.10-11** Tsutsumi, H. and Hanada, K., **Development of 450 tons mechanical vibrator and data acquisition: analysis system in situ,** *CRIEPI Report E377011,* Civil Engineering Lab., Central Research Inst., Japan Electric Power Industry [Abiko], Aug. 1978, 18.

This paper describes a 450-ton mechanical vibrator and data acquisition analysis unit recently developed by the Central Research Inst. of the Japan Electric Power Industry. The system can be used for in-situ vibration tests to investigate the dynamic characteristics of large, complex structures. The system consists of three vibrators with the forces and phases between the vibrators easily controlled. The data acquisition analysis system measures the dynamic behavior of the test structure during the test.

● **6.10-12** Galambos, T. V. and Mayes, R. C., **Lessons from dynamic tests of an eleven storey building,** *Engineering Structures,* **1**, 5, Oct. 1979, 264–273.

Prior to the final demolition of an 11-story reinforced concrete building in St. Louis, Missouri, a part of the building was made available for dynamic testing. The major phases of the testing consisted of (a) a survey of material and dimensional properties; (b) a small amplitude shaking program to determine the initial dynamic properties; (c) large amplitude tests in the E-W direction with the wall cladding in place; and (d) large amplitude tests in the N-S direction with the wall cladding removed. This paper briefly describes the tests and discusses the significance of the test results.

● **6.10-13** Jeary, A. P. and Ellis, B. R., **A study of the measured and predicted behaviour of a 46-storey building,** *Environmental Forces on Engineering Structures,* 121–135. (For a full bibliographic citation, see Abstract No. 1.2-28.)

The response of a 46-story, 190 m tall building to both controlled forcing of oscillation and to the wind has been monitored. Measurements of the building's characteristics, together with the measured wind characteristics at the time of the tests have been used in three design guides. It has been found that none of these guides perform well in this case. Three possible reasons contributing to the discrepancies have been put forward, and areas of research necessary to overcome the problems have been suggested.

6.11 Experimental Facilities and Investigations

● **6.11-1** Yoshioka, K., Okada, T. and Takeda, T., **Study on improvement of earthquake-resistant behaviors of reinforced concrete column (Part 1: experimental study on the arrangement of main bars and web reinforcement to give columns large ductility)** (in Japanese), *Transactions of the Architectural Institute of Japan, 279,* May 1979, 53–63.

Reinforced concrete columns often develop shear failure, bond failure, or flexural compression failure without sufficient ductility after flexural yielding. In this study, the relationship between ductility and such structural details as the arrangement of main bars and axial load levels is clarified. The experiment covered shear span ratios of 1 to 2 and tensile reinforcement ratios of 0.34 ~ 1.44%. The following conclusions are drawn from the test results of 19 columns subjected to bending moment and shear and axial forces.

(1) If the tensile reinforcement ratio is as high as about 1%, the existence of many thin main bars enveloped with hoops will not be effective in preventing bond failure; however, the existence of thick main bars at the corner of welded or rectangular spiral hoops prevents a small degree of bond failure. (2) Bond failure can be prevented and ductility improved by restraining all main bars with either welded hoops or rectangular spiral hoops and supplementary ties. (3) In circular columns with circular spiral hoops, flexural compression failure is prevented and columns exhibit a large degree of ductility, even when the axial stress coefficient is of the order of 1/2 or 1/3. Circular spiral hoops are also effective for the prevention of bond failure.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **6.11-2** Suzuki, T. and Tamamatsu, K.-I., **Experimental study on energy absorption capacity of columns of low steel structures (Part 2: energy absorption capacity of H-shaped steel columns subjected to cyclic loading with varying deflection amplitudes)** (in Japanese), *Transactions of the Architectural Institute of Japan, 280,* June 1979, 19–25.

This series of experiments investigates the energy-absorption capacity of H-shaped steel columns subjected to earthquake loads. The energy-absorption capacity of structures subjected to cyclic loading with varying deflection amplitudes is affected by deflection and lateral deformation. The study clarifies the fact that the cumulative damage rule should be applied to varying loads by using the relationship between energy-absorption capacity and plastic deflection amplitudes of columns subjected to monotonic and cyclic loadings with constant deflection amplitudes.

● **6.11-3** Porter, M. L. and Greimann, L. F., **Pilot tests of composite floor diaphragms**, *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 873–897.

A facility was designed and fabricated for testing composite floor slabs subjected to large in-plane shear forces. Two full-scale 15 ft (4.58 m) square composite floor slabs were tested. Both specimens were constructed using 3 in. (76 mm) deep corrugated cold-formed steel decking with a 2 1/2 in. (64 mm) superimposed fill of normal weight concrete. The slabs were attached compositely to the support beams of the test facility via stud shear connectors. Specimen 1 was loaded monotonically until reaching the maximum load and followed by incremental displacement further into the nonlinear region. Specimen 2 was loaded cyclically under increasing displacement limits. Both specimens failed as a result of diagonal tension cracking of the concrete. The cyclically loaded specimen had approximately the same maximum load and stiffness as the monotonically loaded specimen, but its ductility capacity was smaller.

● **6.11-4** Rainer, J. H., **Dynamic testing of civil engineering structures**, *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 551–574.

The use of dynamic testing of structures in research and engineering applications is described. These include confirmation of mathematical models, determination of damping, motion studies under wind and earthquakes, and short-term and long-term observation of structural behavior under dynamic loadings. Instrumentation requirements, selection and placement of transducers, and recording of the signals on FM, digital, and paper recorders are considered. Filtering, signal-to-noise ratio and analysis and interpretation of data are discussed.

● **6.11-5** Mirza, M. S., Harris, H. G. and Sabnis, G. M., **Structural models in earthquake engineering**, *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 511–549.

This paper presents a brief state-of-the-art report on the use of structural models in earthquake engineering studies. Similitude requirements and dynamic properties of some commonly used materials are summarized. Some of the recent developments in testing techniques and laboratory facilities in North America, Europe, and Japan are briefly reviewed. Four examples of the use of structural models for earthquake-resistant design are presented.

● **6.11-6** Wilson, J. C., Tso, W. K. and Heidebrecht, A. C., **Seismic qualification by shake table testing**, *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 493–510.

This paper examines the seismic qualification of equipment for nuclear power plants using shaking table test methods. The response of a nuclear reactor structure to an earthquake is used to present the concept of floor response spectra for various equipment locations throughout the structure. The floor response spectra are used as the basis for developing shaking table tests to examine the functional capabilities of reactor safety system components mounted at these locations. Current test methods are discussed, and certain advantages and limitations are pointed out. A case history illustrates the use of single-frequency testing in the seismic qualification of a diesel engine. Comments are made on problems currently faced in providing meaningful qualification tests and on possible areas for future research.

● **6.11-7** Williams, D. and Godden, W., **Seismic response of long curved bridge structures: experimental model studies**, *Earthquake Engineering & Structural Dynamics,* **7**, 2, Mar.–Apr. 1979, 107–128.

This paper presents the results of a shaking table study conducted on the seismic behavior of curved reinforced concrete bridge structures used in highway interchanges. A series of representational 1/30th-scale models was constructed in microconcrete to study the effects of both linear and nonlinear dynamic behavior, the nonlinearity including sliding and impacting at the expansion joints and ductility in the columns. Each model was subjected to a series of increasingly severe simulated earthquakes in the longitudinal and transverse directions, both with and without the vertical component. Response data were recorded in the form of selected displacement time histories which were subsequently used as control data in a companion theoretical study. Each model eventually was taken to failure which consisted primarily of extensive damage at the expansion joints. The paper concludes with general observations on the seismic behavior of long-span, long-period curved bridges, and emphasizes the sensitivity of this behavior to the location and design of the joints.

● **6.11-8** Aswad, A., **Selected precast connections: low-cycle behavior and strength,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1201–1224.

This paper presents test results of eight common precast member connections. The testing program was conducted on full-size panels. Testing consisted of static, monotonic, or cyclic loading to failure. Three cycles were applied, each approximately eight to ten minutes long. The results are summarized in tabular form and provide information on the maximum force attained, secant stiffness, and material strengths. While a general analytical model is not derived, comments are included to allow a better understanding of connection behavior and strength. It is found that connection capacities are higher than the values obtained from current conservative methods, since the plate bearing (when available) and mesh contributions are usually neglected.

● **6.11-9** Hidalgo, P. A. et al., **Seismic behavior of concrete block masonry piers,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1253–1275.

Experiments were conducted to evaluate the seismic resistance of window piers typical of highrise concrete block masonry construction. Twenty-four fixed ended piers were subjected to cyclic in-plane shear loads. Principal test parameters were the height-to-width ratio, the amount of vertical and horizontal reinforcement, and the effects of full and partial grouting. Results include an identification of the principal modes of failure, the ultimate strength associated with the modes of failure, and the effect of the test parameters on the ultimate strength. The results also include a discussion of the methods used to predict the strength associated with each of the modes of failure and a discussion of the inelastic characteristics of piers exhibiting the shear mode of failure. In particular, the effects of horizontal reinforcement and partial grouting on the shear mode of failure are emphasized.

6.11-10 Walter, P. L. and Nelson, H. D., **Limitations and corrections in measuring structural dynamics,** *Experimental Mechanics,* **19,** *9,* Sept. 1979, 309–316.

This paper examines the limitations encountered in measuring the dynamic characteristics of structural systems. Structural loading and response are measured by transducers characterized by multiple resonant frequencies where peaks occur in the magnification factor of the transfer function. The transfer function of a transducer is the ratio of the Fourier transform of the output to the Fourier transform of the input causing that output. The magnification factor of the transfer function of a transducer is the factor by which the zero-frequency response must be multiplied to determine the magnitude of the steady-state response at any given frequency. The presence of multiple peaks in the transfer function of a transducer indicates a potential for problems when the transducer responds to a transient stimulus. The problem is more severe if the stimulus contains significant amplitude at frequencies near these peaks, since distortion of the recorded signal will occur. If the transfer function of the transducer is completely characterized, data distortion can be corrected by an inverse treatment. This inverse problem consists of determining the corresponding excitation associated with a particular system model and a given response. Even though measurement difficulties encountered when using transducers with multiple resonant peaks generally cannot be solved by an inverse treatment, procedures are described in this paper which can be applied on a frequency-selective basis to acquire valid data.

● **6.11-11** Kahn, L. F. and Hanson, R. D., **Infilled walls for earthquake strengthening,** *Journal of the Structural Division, ASCE,* **105,** *ST2,* Proc. Paper 14364, Feb. 1979, 283–296.

Five one-half scale reinforced concrete frames were constructed and tested under static reversed cycle loads to determine experimentally the effectiveness of infilled walls in strengthening and stiffening existing framed structures against earthquake loads. An unstrengthened portal frame and a frame with a monolithically cast infilled wall provided references for the three strengthening techniques. The first wall was cast in place within the existing frame; the second was a single precast panel that was bolted to the top and bottom beams; and the third was made of six individual precast panels that were connected to the top and bottom beam and to each other. Tests showed that the cast-in-place wall strengthened the frame so that its capacity was similar to the monolithically cast specimen but that the cast-in-place system dissipated only one-half the energy. The multiple precast panel wall demonstrated greater ductility than the other infilled structures, although its maximum load capacity was about one-half that of the monolithically cast specimen.

● **6.11-12** Tang, D. T. and Clough, R. W., **Shaking table earthquake response of steel frame,** *Journal of the Structural Division, ASCE,* **105,** *ST1,* Proc. Paper 14324, Jan. 1979, 221–243.

● *See **Preface**, page v, for availability of publications marked with dot.*

Earthquake responses of a 17-ft 4-in. (5.29-m) tall three-story steel frame structure were produced in two series of shaking table tests: (1) yielding initiated in the panel zones of joints; and (2) yielding that occurred exclusively at column and girder ends of the structure. The test data are used in the development and verification of analytical procedures. Mathematical models are formulated by first defining the element properties and then assembling them to obtain the system properties. Panel zone deformability, bilinear strain-hardening plastic hinges, and foundation flexibility are considered in the modeling. The model with its parameters rationally determined either analytically or experimentally proves to be adequate in predicting global and local response histories of the structure undergoing elastic and inelastic seismic responses. Because the predicted local deformations are found to be very sensitive to the specified yield mechanisms, it is concluded that exact predictions of damage levels in typical seismic response analyses of structures cannot generally be made.

● **6.11-13** Sim, L. C. and Berrill, J. B., **Shaking table tests on a model retaining wall,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 301–311.

Shaking table tests of a model gravity retaining wall are described. The tests were designed to check the validity of the simple analytical model of wall behavior proposed by Elms and Richards in a companion paper. The results show that the wall translates outward in a stepwise fashion under strong shaking as predicted by the analytical model.

● **6.11-14** Priestley, M. J. N. et al., **Dynamic performance of brick masonry veneer panels,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 441–457.

Dynamic tests on seven unreinforced and two reinforced brick masonry veneer panels are reported. The panels, tied to conventional timber-frame backings, were subjected to inertial loading by sinusoidal accelerations within the expected range of seismic frequencies. Variables investigated included stud spacing, veneer-tie type, and initial distribution of preformed cracking. The results indicate that properly constructed brick masonry veneers can withstand seismic levels substantially in excess of that implied by New Zealand Standard NZS 4203 for Zone A with only minor cracking.

● **6.11-15** Blakeley, R. W. G. et al., **Cyclic load testing of two refined reinforced concrete beam-column joints,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 459–492.

This paper describes the testing of two reinforced concrete beam-column joint units tested under incremental static cyclic loading. The full-size test units were based upon an interior beam-column joint of a four-story framed building designed to the current New Zealand (NZ) loading code. The test units are refinements of two previously tested conventional joints of similar dimensions. One unit differed from common practice by having a post-tensioned beam stressed to balance the floor dead load of the prototype structure. The second unit was detailed with haunched beams. Hinge formation occurred in the beams, and stable hysteretic behavior was obtained up to displacement ductilities of 10 for the prestressed unit and 6 for the haunched unit. The test results are analyzed in terms of the draft NZ design code, DZ 3101, and the ACI recommendations for beam-column joint design.

● **6.11-16** Park, R. and Keong, Y. S., **Tests on structural concrete beam-column joints with intermediate column bars,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 513–532.

Three structural concrete interior beam-column joint units were tested. The beams were prestressed by tendons in the top and the bottom of the section but not at middepth. The columns were reinforced using Grade 380 longitudinal bars. Transverse shear reinforcement existed in all members and in the joint core. Static cyclic loading was applied to the units to simulate seismic loading. The presence of intermediate column bars is shown to significantly improve the shear capacity of the joint core. The need for a relatively small neutral axis depth in the plastic hinge regions of beams for ductile behavior is emphasized.

● **6.11-17** Fenwick, R. C. and Fong, A., **The behavior of reinforced concrete beams under cyclic loading,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 533–552.

The behavior of beams in which plastic hinges are formed under cyclic loading is examined. The results are reported of five beam tests with varied shear stress levels. It is shown that even relatively low shear stress levels have a significant influence on beam behavior. Two main effects of shear are to reduce the ability of the hinge to dissipate energy and to reduce the stiffness of the beams at low load levels. The degradation in shear under cyclic loading is accompanied by an appreciable growth in the length of the beams.

● **6.11-18** Tomlinson, G. R., **Force distortion in resonance testing of structures with electro-dynamic vibration** exciters, *Journal of Sound and Vibration*, 63, 3, Apr. 8, 1979, 337–350.

Harmonic input force distortion which arises when systems are excited with electro-dynamic exciters is shown to be predominantly second harmonic, the major source of the harmonic distortion being a result of the vibration exciter characteristics. These characteristics are examined by experimentally determining the magnetic field strength properties of a typical exciter, and the results show these to be a nonlinear, even function. This information is used with the equations of motion of the exciter which are simulated on an analog computer. The computer force characteristics are shown to compare well with experimental results. The amount of second harmonic force distortion generated at a system resonance is analyzed by considering a simple single degree-of-freedom model. It is shown that the amount of force distortion is related to the damping of the system under test and the ratio of the exciter stiffness to the system stiffness. It is also shown that the force input to a system near a system resonance can vary considerably, even though the input current to the exciter is constant. These effects are shown to be caused by the forces arising from the mass and stiffness characteristics of the exciter being used. Experimental tests on a simple system confirm the theoretical predictions.

● **6.11-19** Aristizabal-Ochoa, J. D., Shiu, K. N. and Corley, W. G., **Effects of beam strength and stiffness on coupled wall behavior,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 323–332.

Results are presented of an experimental investigation to determine effects of coupling beam strength and stiffness on the overall response of two reinforced concrete coupled wall systems subjected to earthquake-like loadings. The objectives of the investigation were to evaluate the effects of axial load induced by the coupling beams on behavior of the individual walls, and the effects of the coupling beams on crack development, general behavior, and the yielding sequence. In addition, the performance of walls and connecting beams was evaluated based on previous tests of the individual elements. Conclusions are drawn about existing procedures for analyzing and designing coupled wall systems.

● **6.11-20** Sterett, J. B. and Watson, C. E., **Large scale vibration testing of engineering structures,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 333–342.

Application to earthquake engineering problems of the aerospace industry's large-scale vibration testing techniques of engineering structures is feasible and practicable. Earthquake and aerospace engineering analytical techniques have limited capabilities to accurately predict local effects, nonlinearities, and damping; thus, empirical results from large-scale tests are extremely valuable. Earthquake research projects at the Marshall Space Flight Center, U.S. National Aeronautics and Space Admin., could provide valuable new data by using the unique large structures, special equipment, data systems, and experience of the personnel at the center.

● **6.11-21** Krawinkler, H., **Possibilities and limitations of scale-model testing in earthquake engineering,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 283–292.

This paper presents an overview of dynamic modeling theory and the types of scale models that may be useful for dynamic studies in earthquake engineering. The emphasis is on modeling of buildings but some attention is given to the possibilities and limitations of scale-model testing for other civil engineering systems.

● **6.11-22** Hidalgo, P. A. and McNiven, H. D., **Seismic behavior of masonry piers,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 303–312.

Results of cyclic lateral load tests on 70 full-scale masonry piers and a summary of the test program are presented. These tests form part of a research program, conducted at the Earthquake Engineering Research Center, Univ. of California, Berkeley, since 1972, to study the seismic behavior of structural members commonly used in multistory masonry buildings. Of the tests described in the paper, the first seven were performed with a double-pier specimen that closely represented the actual boundary conditions of piers found in a perforated shear wall. Spandrel girders constrained the top and bottom sections of the piers against rotation, forcing the piers to deform in double curvature. Constructed from standard two-core, reinforceable hollow concrete blocks, 6 in. wide by 8 in. high by 16 in. long, the piers had a height-to-width ratio of 2 (64 in. to 32 in.).

● **6.11-23** Gulkan, P. and Mayes, R. L., **An experimental investigation of the reinforcement requirements for simple masonry structures in moderately seismic areas of the U.S.,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 293–302.

● *See **Preface**, page v, for availability of publications marked with dot.*

This paper presents an overview of an experimental investigation of the seismic reinforcement requirements for single-story masonry dwellings. The promulgation of a "local acceptable standard" by the U.S. Dept. of Housing and Urban Development (HUD) Phoenix, Arizona, office requiring partial reinforcement in masonry houses was questioned by individuals associated with the local housing industry on the grounds that the standard was not rational and that compliance with it would lead to higher costs and unnecessarily large factors of safety for seismic loads. To address this question, the investigation, undertaken at the request of HUD, was aimed at providing information on the behavior of simple masonry structures subjected to simulated earthquakes. The objective was to determine reinforcement requirements for adequate resistance of typical masonry housing construction for the level of seismic activity expected in Seismic Zone 2 areas of the 1973 Uniform Building Code. A unique feature of the investigation was the testing of full-scale structural components of typical masonry houses on the Univ. of California, Berkeley, shaking table.

● **6.11-24** Tissell, J. R., **Design considerations for plywood diaphragms in Seismic Zone 4,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 953–958.

Full-scale (16- x 48-ft) diaphragm tests were conducted to provide the research background for this paper. Eleven diaphragms were tested. The test included such design considerations as the high density of fasteners, openings, glued diaphragm construction, and two-layer systems in the high shear areas. Only four diaphragms of conventional construction and high-density mechanical fasteners are discussed in this report.

● **6.11-25** Aswad, A., **Selected precast connections: low-cycle behavior and strength,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1085–1094.

To study common precast member connections, the author conducted experiments on full-sized panels. In this paper, the results of tests of six connections are described. Testing consisted of static, monotonic, or cyclic loading to failure, with the number of full cycles limited to three and the duration of each cycle limited to approximately ten minutes. The results, summarized in tabular form, provide information on the maximum force attained, secant stiffness, and material strengths. No attempt has been made to derive a general analytical model, but comments are included to better understand connection behavior and strength. Connection capacities were found to be higher than the values obtained from current conservative methods because plate bearing and mesh contribution were usually neglected.

● **6.11-26** Kahn, L. F. and Suriano, B. J., **Improving ductility of existing reinforced concrete columns,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1095–1103.

The purpose of the experimental research described in this paper was to study three simple and potentially inexpensive techniques for strengthening existing reinforced concrete columns. The scope was limited to testing four 10-in. square columns, three of which were strengthened using different methods to confine the concrete. A qualitative comparison of the behavior of the four columns was the primary objective. The column specimens represented only one type of column construction which might require strengthening, and the techniques used provide only a starting point for evaluating retrofit construction. While research in the area of repair and strengthening is increasing, past work by Higashi and Kokusho demonstrated some strengthening techniques.

● **6.11-27** Mills, R. S., Krawinkler, H. and Gere, J. M., **Model tests on earthquake simulators: development and implementation of experimental procedures,** *Report 39,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, June 1979, 272.

For problems which involve complex structures with material and/or geometric nonlinear behavior, the practical capabilities of mathematical methods of analysis may be surpassed. In such cases, experimental analysis may serve as an alternative and as a means of extending the limits of theoretical knowledge. Essential to accurate experimentation in earthquake engineering is an adequate dynamic test facility consisting of suitable excitation sources (e.g., an earthquake simulator), instrumentation and a minicomputer system for signal generation, data acquisition, and data reduction. Because of size constraints, testing of complete structures in the laboratory will often be limited to small-scale models. The necessary capabilities of a test system for dynamic model studies are discussed and illustrated by reference to the facilities at the John A. Blume Earthquake Engineering Center at Stanford Univ.

An actual model test serves to illustrate the accuracy of replica modeling, to assist in the development of testing methodologies, and to evaluate the adequacy of a dynamic test facility. In order to develop confidence in the ability of a small-scale model to replicate structural response to earthquakes, it was desirable to have a well-defined prototype with documented dynamic properties for correlation of model response. Thus, a three-story, single-bay steel frame structure previously tested on the shaking table at

● *See **Preface**, page v, for availability of publications marked with dot.*

the Univ. of California, Berkeley, was used as a prototype for a 1:6 scale model study. The primary task in the development of a replica model is to simulate all aspects of the prototype structural system which may contribute to the earthquake response characteristics. One modeling method which is applicable to a great number of building structures where gravity effects must be included is artificial mass simulation. Such modeling involves the addition of structurally uncoupled mass to augment the density of the model structure, permitting the choice of a model structural material without regard for mass density scaling. The model wide-flange sections were machined from A36 steel bar stock and primary structural connections were fully welded, utilizing the TIG heliarc process. Subsequent heat treatment of the finished model frames was performed to relieve high initial stresses and to satisfy construction tolerances which were derived from geometric scaling of standard tolerances for building structures. A comprehensive test study, encompassing material, subassembly, and earthquake simulator tests, was performed to enable an accurate comparison of model and prototype response. Earthquake simulator tests utilized the El Centro 1940 north-south component and an artificial earthquake composed of discrete spectral components to excite the structure both elastically and inelastically.

The results of the model test series are discussed in detail. Accurate simulation of the prototype structure in terms of global and local response parameters was achieved. The nature of prototype inelastic response was duplicated by the small-scale model as characterized by yielding of the joint panel zones in shear and by comparison of the ductility demand and energy distribution of the respective structures. Observed minor discrepancies in model-prototype correlation can be explained by the larger weld sizes of the model and by the influence of earthquake simulator reproduction capabilities on test structure response.

● **6.11-28** Humar, J. L., **Composite beams under cyclic loading,** *Journal of the Structural Division, ASCE,* **105,** *ST10,* Proc. Paper 14897, Oct. 1979, 1949-1965.

Test specimens consisting of a steel column stub and a composite steel-concrete beam are tested under cyclic loading. The results show that composite beams subjected to cyclic loading exhibit stable hysteresis loops and good ductility. The behavior under negative moment is governed by the local buckling of the beam flanges and the web. Beams with horizontal web stiffeners or stocky webs show marked increase in ultimate strength and ductility under negative moment.

● **6.11-29** Nelson, D. J., **Dynamic testing of discontinuous fibre reinforced composite materials,** *Journal of Sound and Vibration,* **64,** *3,* June 8, 1979, 403-419.

The work reported in this paper is part of a larger study of the mechanics of discontinuous fiber reinforced composite materials—particularly those with interfacial slip. The materials used were models composed of aligned stub steel rods of 0.4-mm diameter and 25-mm length as the fibers and a proprietary silicone rubber as the matrix. The specimens, which were of a low-volume fraction (~7.5%), were in the form of square section rods and had either bonded or unbonded matrix/fiber interfaces. The tests conducted consisted of simple strain-controlled tensile tests at 0.83 Hz and 0.083 Hz and the use of the specimens as the spring/damper element in a single degree-of-freedom system resonating near 20 Hz. In the latter tests, the damping in the system extraneous to the specimen was quite high and, in the case of the bonded specimens, a correction had to be made. Both the damping and stiffness of all the specimens were broadly dependent upon the amplitude of oscillation. In all of the single degree-of-freedom system tests, softening resonances were exhibited, but in the case of the bonded specimens, this was a result of the nature of the matrix, while for the unbonded specimens reduction in stiffness with increase in amplitude was a result of sliding at the interface. The specimens were designed to investigate this latter effect, which also caused a substantial increase in damping and led to flat-topped resonance curves characteristic of a system containing friction. The tests further exhibited the rate sensitivity of the properties of the unbonded interface specimens which showed higher stiffness and lower damping in the resonance tests than in those at lower frequencies. It was concluded that a discontinuous fiber composite developed for its damping properties would be most effectively achieved in a composite where there was a good bond at the interface and the matrix damping increased greatly with an increase in shear or rate of deformation.

6.11-30 Lifshitz, J. M. and Gilat, A., **Experimental determination of the nonlinear shear behavior of fiber-reinforced laminae under impact loading,** *Experimental Mechanics,* **19,** *12,* Dec. 1979, 444-449.

A procedure is developed for the experimental determination of the nonlinear shear behavior of fiber-reinforced composites by testing angle-ply laminates. It is shown that, for the E glass/epoxy used in this work, the popular ± 45 degree specimens fail prematurely because of transverse stresses, thus limiting the range for which the shear stress-strain curve can be obtained. By selecting an appropriate fiber orientation, ± 41 degree in the present work, premature failure can be prevented and the nonlinear shear response can be obtained almost to shear failure. The experimental program involved four groups of tensile specimens (± 30, ± 35, ± 41, and ± 45 degree) tested under impact conditions using a drop weight testing machine. Analysis was performed using classical plate theory and an incremental loading procedure. Some problems involved in

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

conducting dynamic tests are discussed and a solution is presented.

● **6.11-31** Vargas Neumann, J., **Rural adobe dwellings** (Vivienda rural en adobe, in Spanish), *DI-78-01*, Dept. de Ingenieria, Pontificia Univ. Catolica del Peru, Lima, 1978, 18. (Paper originally presented at the 19th Jornadas Sudamericas de Ingenieria Estructural, Santiago, 1978.)

This report describes a research program carried out to study the structural behavior of rural adobe houses under seismic excitation. A series of static tests was performed. Results, observations, and conclusions are included.

6.11-32 Korenev, B. G. and Blekherman, B. G., **Experience in damping vibrations of a tower structure** (Opyt gasheniya kolebanii bashennogo sooruzheniya, in Russian), *Stroitel'naya mekhanika i raschet sooruzhenii, 1*, Feb. 1979, 50-51.

An experiment employing dynamic vibration dampers in the design and erection of slender tower structures (such as smokestacks, exhaust stacks, and television towers) is described. The results of the full-scale test data are described.

● **6.11-33** Liauw, T. C., **Tests on multistory infilled frames subject to dynamic lateral loading**, *Journal of the American Concrete Institute*, **76**, *4*, Title No. 76-26, Apr. 1979, 551-563.

An experimental investigation is presented of the dynamic lateral load tests of four-story models of steel frames with reinforced concrete infills. Various factors, e.g., the provision of shear connectors between the frames and the infills, together with the effect of openings in the infills, are examined in terms of the strength and stiffness of the models. The crack patterns and the modes of failure of the models are important features to be noted in relation to the dynamic behavior of infilled frames. The shear connectors play a vital role in improving the strength and stiffness of the infilled frames, whereas the presence of openings in the infills reduces considerably the capacity of the structures to withstand dynamic loading.

● **6.11-34** Mansur, M. A. and Rangan, B. V., **Experimental investigation of reinforced concrete spandrel beams**, *UNICIV Report R-177*, School of Civil Engineering, Univ. of New South Wales, Kensington, Australia, Aug. 1978, 71.

A test program was conducted to investigate five different methods of designing a reinforced concrete spandrel beam. The program consisted of testing 13 T-shaped specimens representing the spandrel-floor beam system both at midspan and endspan regions of a continuous spandrel beam. Five specimens were tested under repeated loading. Test results and a comparison of the amount of steel required by different methods show that the ACI limit design method gives a satisfactory and economic design for the entire length of the spandrel.

● **6.11-35** Kitajima, S. and Uwabe, T., **Analysis on seismic damage in anchored sheet-piling bulkheads** (in Japanese), *Report of the Port and Harbour Research Institute*, **18**, *1*, Mar. 1979, 67-127.

Seismic damage to anchored sheet piling bulkheads located in 22 ports subjected in the past to strong earthquakes is analyzed. The behavior of the bulkheads during earthquakes and their failure process were observed by means of a series of vibration model tests. Conclusions reached in this paper are as follows. (1) The design procedure for bulkheads, authorized in the design standard for port structures, is adequate from a practical viewpoint. The necessity of modifying the procedure concerned with bulkheads with flexible anchors is discussed, and a possible modification is proposed. (2) The relationship between the seismic coefficient and the maximum ground acceleration applied for gravity quaywalls is applied correspondingly to the bulkheads. (3) The damage during earthquakes is caused by the movement of the anchorages if the bulkheads are designed adequately. Careless reinforcement of only the anchorages leads to complete failure. (4) The movement is caused by intense tie-tension fluctuating widely within a narrow band of special frequencies of 2 to 4 Hz.

● **6.11-36** Yamada, M. and Kawamura, H., **Resonance fatigue characteristics of structural materials and structural elements (Part VI: aseismic structural test; fundamental concept and method)** (in Japanese), *Transactions of the Architectural Institute of Japan, 285*, Nov. 1979, 93-99.

In this paper, a method for seismic-resistant structural testing is proposed to aid in the ultimate design of structures as introduced in an earlier paper. The purpose of the test is to determine the resonance-fatigue characteristics of structures under two conditions, the symmetry of origin and the resonance response. The main factors to be measured and a typical descriptive format are shown in tabular form.

● **6.11-37** Woodward, K. A. and Jirsa, J. O., **Design and construction of a floor-wall reaction system**, *CESRL Report 77-4*, Structures Research Lab., Dept. of Civil Engineering, Univ. of Texas, Austin, Dec. 1977, 71.

This report documents and describes the conception, design, and construction of the floor-wall reaction system designed and built by the Civil Engineering Structures Research Lab. at the Univ. of Texas, Austin. The system was constructed to enable researchers to test large-scale models using bilateral loadings in addition to axial loads.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 6.11-38 Jirsa, J. O., Maruyama, K. and Ramirez, R., **Development of loading system and initial tests—short columns under bidirectional loading,** *CESRL Report 78-2,* Structures Research Lab., Dept. of Civil Engineering, Univ. of Texas, Austin, Sept. 1978, 70.

The object of this report is to describe the special loading facilities developed for the application of bidirectional lateral loads and varying axial loads (tension and/or compression) on short columns failing in shear. The design of the specimen is discussed and the instrumentation used to monitor the behavior is described. Finally, the results of four test specimens are presented to give an indication of the capabilities of the loading and data acquisition systems developed.

● 6.11-39 Krawinkler, H. et al., **Experimental study on the seismic behavior of industrial storage racks,** *41,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Nov. 1979, 147.

This report discusses the development of loading criteria, the testing and the interpretation of test results for a series of experiments on full-sized rack assemblies, subassemblies and rack components. Forced vibration tests as well as quasi-static monotonic and cyclic loading tests to failure were carried out. The forced vibration tests are needed to obtain information on natural frequencies, mode shapes, and damping characteristics, while the behavior of connections and members as well as the stability of the frame-type racks are studied from cyclic loading tests. The objectives of the study summarized in this report are (1) the determination of the load-deformation response of cold-formed steel members and their connections under cyclic loading similar to that expected under severe seismic excitations; (2) the development of mathematical models of response characteristics as needed for subsequent analytical studies; and (3) the development of standardized seismic testing procedures which can be utilized by the rack manufacturing industry for seismic qualification testing.

● 6.11-40 Yao, J. T. P., **An approach to damage assessment of existing structures,** *Technical Report CE-STR-79-4,* School of Civil Engineering, Purdue Univ., West Lafayette, Indiana, Oct. 1979, 25.

In this report, an attempt is made to explore the application of fuzzy sets as an alternative and/or supplementary approach for assessing the damage to existing structures. This proposed methodology can be used to incorporate the experience, intuition, and judgment of various experts who may be willing to share their valuable knowledge in advancing the state-of-the-art of the engineering profession.

● 6.11-41 Lee, L. H. N. and Ng, D. H., **Dynamic yielding of tubings under biaxial loadings,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 105-115. (For a full bibliographic citation, see Abstract No. 1.2-16.)

A test vehicle described in this paper has been developed for applying biaxial, tension-internal pressure loading to thin-walled tubular specimens over a range of loading rates. The dynamic responses as well as static initial and subsequent yield surfaces of a number of specimens made of 6061-T6 aluminum alloy are presented. The stress path obtained in a dynamic biaxial test was reproduced statically. The corresponding stress-strain curves are compared and are found to be significantly different. It is also found that the dynamic initial yielding occurs at a higher state of biaxial stress, depending on the loading rate, than does static yielding.

● 6.11-42 Gauvain, J. et al., **Tests and calculation of the seismic behaviour of concrete structures,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper examines frame-type nuclear power plant structures. Described are the main phenomena governing the behavior of such structures when the earthquake level increases up to the point of structural collapse, the type of analytical model for obtaining good results, and an estimation of the safety factors corresponding to usual design practice. Also described are the shaking table tests of simple beams and frames.

● 6.11-43 Donten, K. et al., **The results of dynamic tests on 1:10 model of containment for nuclear reactor,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 13/10, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Tests were carried out on a 1/10-scale model of a prestressed concrete reactor containment structure. The impact method and the acoustic method were used to generate vibrations. When the impact method was used, nonharmonic vibrations, which were quickly damped, occurred in the model. These vibrations were subjected to harmonic analysis. When the acoustic method was used, the model was forced to a constant vibration at a frequency equal to the sound wave frequency. Resonance was established at frequencies similar to those of the harmonic components found in the first stage of testing. The types of vibrations with which resonance occurred were defined, and the damping factor of the structure was established.

● 6.11-44 Muto, K., Kuroda, K. and Kasai, Y., **Forced vibration test of 1/5 scale model of CANDU core,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/3,

● *See **Preface**, page v, for availability of publications marked with dot.*

10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A seismic verification program has been undertaken for a CANDU nuclear reactor planned for Japan. The program will consist of two stages: Step I will involve tests of a 1/5-scale, half-cut model of the core and Step II will involve tests using partial full-scale models of the core. This paper presents the test results for Step I. The tests were intended to clarify the basic characteristics pertinent to the seismic behavior of tube assemblies in water and the insertion capability of control shutoff rods during an earthquake. The test model selected was a half portion of the core and cut vertically so that the actual behavior of the inside components could be observed. The tests were conducted using a large shaking table.

● **6.11-45** Blackwell, F. N., **A study of the earthquake resistance of domestic break pressure tanks,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *2,* June 1979, 168–173.

The paper reports on a series of dynamic tests on possible restraint systems for domestic break pressure tanks and recommends the use of wire guys if bracket supports cannot be rigidly attached to the tank walls.

● **6.11-46** Hidalgo, P. A. et al., **Cyclic loading tests of masonry single piers; Volume 3–height to width ratio of 0.5,** *UCB/EERC-79/12,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 153. (NTIS Accession No. PB 301 321)

This report presents the results of eighteen cyclic, in-plane shear tests on fixed-ended masonry piers having a height-to-width ratio of 0.5. These eighteen tests form part of a test program consisting of eighty single pier tests. Previous reports have presented the results of forty-five piers having height-to-width ratios of 2 and 1 and a subsequent report will present the test results of the remaining seventeen piers. The test setup was designed to simulate, insofar as possible, the boundary conditions the piers would experience in a perforated shear wall of a complete building. Each test specimen was a full-scale pier 40 in. high and 80 in. wide. Three types of masonry construction were used: a hollow concrete block, a hollow clay brick type that used an 8-in.-wide unit, and a double wythe grouted core clay brick, 10-in.-thick wall that consisted of two wythes 3 1/2 in. thick and a 3-in. grouted core. The variable included in the investigation was the quantity of horizontal reinforcement. All the piers were fully grouted. The results are presented in the form of hysteresis envelopes, graphs of stiffness degradation, energy dissipation and shear distortion, and tabulated data on the ultimate strength and hysteresis indicators. A discussion of these test results is presented but no definitive conclusions are offered. These will be included in a final report at the completion of the eighty tests.

● **6.11-47** Gulkan, P., Mayes, R. L. and Clough, R. W., **Shaking table study of single-story masonry houses, Volume 1: test structures 1 and 2,** *UCB/EERC-79/23,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1979, 260.

Earthquake damage to masonry construction during recent years underscores the need for a better understanding of the seismic response of these structures and the establishment of rational reinforcement requirements. An experimental investigation aimed at determining reinforcement requirements for single-story masonry dwellings in Uniform Building Code Seismic Zone 2 areas of the United States has been completed at the Univ. of California, Berkeley. The experimental results of the investigation are presented in Volumes 1 and 2, while Volume 3 will contain conclusions from the tests as well as recommendations for reinforcement requirements for masonry houses based on realistic seismic conditions for Zone 2.

The overall study included the testing of four masonry houses, with both unreinforced and partially reinforced wall panels, assembled to form 16-ft-square models of typical masonry houses. The masonry units utilized in the construction of all test structures were full-sized units. Each house was provided with a timber truss roof structure to which weights were attached so as to obtain realistic loads on the bearing walls. Methods, models, and test facilities utilized in the study are described. A detailed description of the measured response of each test structure is provided, and a quantitative assessment of parameters affecting the response is presented, in this volume for Houses 1 and 2, and in Volume 2 (see Abstract No. 6.11-48) for Houses 3 and 4. The tests show that partially reinforced walls demonstrate excellent behavior under all levels of base excitation applied during the tests.

● **6.11-48** Gulkan, P., Mayes, R. L. and Clough, R. W., **Shaking table study of single-story masonry houses, Volume 2: test structures 3 and 4,** *UCB/EERC-79/24,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1979, 248.

For an abstract of this report, see Abstract No. 6.11-47.

● **6.11-49** Sheikh, S. A. and Uzumeri, S. M., **Effectiveness of rectangular ties as confinement steel,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 396–407. (For a full bibliographic citation, see Abstract No. 1.2-21.)

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

The paper presents the results of an experimental program that included testing of 24 short columns with cross sections of 12 in. x 12 in. (305 mm x 305 mm) and 6 ft 5 in. (1960 mm) high. Columns were cast vertically and tested under monotonic axial compression. The core size of all the specimens was 10.5 in. (267 mm) square measured from center to center of the perimeter hoop. Discussed are the contribution to the enhanced load-carrying capacity and the ductility of the confined concrete core, the amount of lateral ties, the distribution of column steel around the perimeter of the core, the configuration of the tie steel and the relationship between the size of the column steel and the size and spacing of the lateral steel that delays the buckling of the column steel.

● **6.11-50** Takiguchi, K. et al., **Study on the restoring force characteristics of reinforced concrete columns to bi-directional displacements—Part 1: development and examination of loading apparatus for testing reinforced concrete columns subjected to bi-directional horizontal forces and axial force** (in Japanese), *Transactions of the Architectural Institute of Japan, 286,* Dec. 1979, 29-35.

This paper describes a newly developed loading apparatus for experimental studies to aid in clarifying the restoring force characteristics of reinforced concrete columns subjected to bidirectional horizontal forces and axial force. The loading method of the apparatus is as follows: (1) The base of a column is attached to the bed of the apparatus. (2) The axial force is vertically applied by dead weight. (3) Two horizontal forces are applied to the top of the column by oil jacks independent of each other. The three relative rotational displacements between the top and the base of the column are restrained by a link mechanism, but the two horizontal displacements and the vertical displacement are not restrained. Three specimens were tested without axial force, in order to obtain fundamental data about the restoring force characteristics of reinforced concrete columns subjected to bidirectional horizontal displacements and to examine the effects of the link mechanism on restraining rotational displacements. Horizontal, vertical, and rotational relative displacements were measured. From these experimental results, it was found that all rotational displacements were negligibly small, but that horizontal and vertical displacements were not restrained at all by the link mechanism. Thus, the loading apparatus was operating properly and was restraining the rotational displacements, as expected.

● **6.11-51** Clough, R. W. and Niwa, A., **Static tilt tests of a tall cylindrical liquid storage tank**, *UCB/EERC-79/06,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1979, 116. (NTIS Accession No. PB 301 167)

This report presents results of a static tilt test investigation of a cylindrical liquid storage tank. The test structure was a 7 3/4 x 15 ft tank model tested previously on the shaking table. The test was performed by mounting the tank on a rigid platform, filling it with water, and tilting the platform by lifting one edge with a laboratory crane. Principal test parameters included water depth, tilt angle, and top condition (open or with roof), but, as in the shaking table tests, the most important parameter was the base fixity condition. Test measurements included tank deformations and membrane stresses. The observed behavior also was compared with results of typical design calculations. An important observation was that the unanchored tank tilts more and develops much greater axial stresses than are indicated by typical design procedures.

6.11-52 Vinokurov, O. P. and Romanovskaya, K. M., **Testing cellular concrete separation walls under horizontal load** (Ispytanie prostenkov iz yacheistogo betona na gorizontal'nye nagruzki, in Russian), *Beton i zhelezobeton, 6,* June 1979, 22-23.

Experimental tests were conducted on the strength and deformability of separation walls subjected to horizontal loads acting in the plane of the walls. Data were obtained on the shear characteristics of cellular concrete, as well as new information on the strength of cellular concrete wall elements and their ability to resist cracking. Outer walls were found to be the most severely seismically loaded elements of large-panel buildings, and failure of separation walls by pullout of the anchoring reinforcements was noted, along with underutilization of the strength of the reinforcements.

● **6.11-53** Nuclear Power Engineering Test Center (Tokyo) [**Large-scale earthquake simulator facilities**], Tokyo, 1977-1979, 3 vols. in 1.

The contents are the following: The aseismic demonstration test facility for large components of nuclear power plants; The aseismic proving tests on the reliability for the equipment and components of nuclear power plants; On aseismic proving test project using a large-scale vibration table.

6.12 Deterministic Methods of Dynamic Analysis

● **6.12-1** Minakawa, Y., **The periodic solution problems of nonlinear equations of motion (Part 1: Review and classification of unknowns in algebraic equations)** (in Japanese), *Transactions of the Architectural Institute of Japan, 276,* Feb. 1979, 59-67.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

Nonlinear vibration problems and basic nonlinear equations of motion are reviewed. Many papers dealing with nonlinear vibrations in elastic systems consider only the Duffing or the Mathieu-Hill equations; the papers disregard the general nonlinear equations of motion obtained by considering the finite deformation theory in elasticity. The Duffing equation corresponds to the stystem for which the nonlinear springs are monotonic functions of displacement and the Mathieu-Hill equation is the approximate equation derived by assuming separate variables. If the general nonlinear equations of motion are adopted as the basic equation for nonlinear vibrations, the treatment of nonlinear vibration problems is unified. In order to classify nonlinear vibrations, it is necessary to comprehend the global unknowns in the algebraic equations; the local unknowns have been studied precisely in static nonlinear stability problems. By application of the theory, the classification of unknowns in the algebraic equations and a global definition of a symmetric bifurcation are constructed.

● **6.12-2** Minakawa, Y., **Nonlinear free vibration in conservative field: the periodic solution problems of nonlinear equations of motion-part 3** (in Japanese), *Transactions of the Architectural Institute of Japan, 278,* Apr. 1979, 9-14.

Periodic solutions are studied of nonlinear autonomous equations of motion with one degree-of-freedom in a conservative field. Considering the relation between shapes of closed orbits on the phase plane and free vibration response shapes of the periodic solutions corresponding to the orbits, the author concludes (1) The approximate periodic solution obtained by applying the cosine Fourier series to the equation of motion in the conservative field uniformly converges to the exact periodic solution. (2) The approximate periodic solution obtained by applying the sine Fourier series does not generally converge to the exact solution. The condition is sought wherein the sine Fourier series expresses the approximate solution which uniformly converges to the exact periodic solution.

● **6.12-3** Minakawa, Y., **Numerical analysis of nonlinear vibrations: the periodic solution problems of nonlinear equations of motion-Part 4** (in Japanese), *Transactions of the Architectural Institute of Japan, 279,* May 1979, 21-27.

A new classification for nonlinear vibrations is given in Parts 1 and 2. In this paper, typical vibrations, classified as accompanying type, branching type (1), and branching type (2), are analyzed. From the numerical results for the accompanying-type vibrations, the behavior of the oscillation components can be ascertained by means of nonlinear terms in the algebraic equations which are derived by applying the method of harmonic balance. Numerical results for one-half subharmonic oscillation classified as branching type (1) show that there is an unstable oscillation region. In conventional treatment of the vibrations in elastic systems, such as branching type (2), the vibrations are considered to be the type of parametric excitations that occur in the Mathieu-Hill equation. The results obtained in this paper are compared with the results obtained by applying the conventional treatment. To examine whether the periodic solutions obtained are stable, a complex eigenvalue problem is solved.

● **6.12-4** Minakawa, Y., **A classification of nonlinear vibrations—the periodic solution problems of nonlinear equations of motion-part 2** (in Japanese), *Transactions of the Architectural Institute of Japan, 277,* Mar. 1979, 45-54.

Nonlinear vibrations which occur in the equations of motion expressed by normal modes are classified into three types. The harmonic balance method is applied to the analysis of the periodic solutions of the equations of motion. The nonlinear vibration problems are expressed by algebraic equations which are composed of Fourier coefficients. The unknowns of the algebraic equations are classified by applying the procedure described in Part 1. Because the unknowns express the Fourier coefficients that represent nonlinear vibrations, the vibrations are classified into three types: accompanying type, branching type (1) and branching type (2). In order to study the stability of the periodic solutions corresponding to undisturbed motion, a complex eigenvalue problem is derived by applying the method of harmonic balance to the variational equations.

● **6.12-5** Minakawa, Y., **The stability of the periodic solution and approximate solutions of nonlinear vibrations: the periodic solution problems of nonlinear equations of motion-Part 5** (in Japanese), *Transactions of the Architectural Institute of Japan, 280,* June 1979, 11-17.

The determination of the stability of periodic solutions of the equations of motion for multidegree-of-freedom systems requires the solving of a complex eigenvalue problem. Approximate periodic solutions of nonlinear equations generally are derived by using such iteration procedures as the Newton-Raphson method. However, some cases can be solved algebraically to yield approximate solutions of nonlinear free and forced vibrations and to determine the boundary regions of instability for subharmonic oscillations and parametric excitations.

● **6.12-6** Masri, S. F., **Evaluation of an approximate seismic analysis technique**, *Bulletin of the Seismological Society of America,* **69**, *2,* Apr. 1979, 603-625.

Exact dynamic responses of a series (3,024 cases) of two degree-of-freedom structure/equipment models subjected to earthquake excitations were determined and compared with responses obtained by a simple approximate seismic analysis technique that is used by design engineers to determine equipment response spectra. The results of

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

the evaluation of errors in estimating the equipment acceleration spectra with approximate solution techniques indicate that for the system under consideration (1) the errors fluctuate over a wide range from overly conservative to highly unconservative without any discernible trend, (2) the predictions of the approximate analysis lack consistency, and (3) the range of validity of the approximate solution technique cannot be ascertained.

● **6.12-7** Zajaczkowski, J. and Lipinski, J., **Vibrations of parametrically excited systems,** *Journal of Sound and Vibration,* **63,** *1,* Mar. 8, 1979, 1-7.

This paper is concerned with a set of linear differential equations with time-dependent parameters given by a trigonometric series. The derived formulas make it possible to examine stability, to find boundaries of the regions of instability, and to estimate the steady-state amplitude response of forced vibrations.

● **6.12-8** Yanev, B. S. and McNiven, H. D., **Mathematical modelling of the seismic response of a one story steel frame with infilled partitions,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 829-846.

The response of a one-story steel frame to earthquake excitations is discussed. The contribution of infilled partitions to the structural behavior is examined. Results of experiments performed at the Earthquake Engineering Research Center, Univ. of California, Berkeley, with one-story steel frames are described. System identification techniques are applied to the experimental data in order to determine physically meaningful parameters representing the behavior of the structure. The effect of highly nonlinear material behavior on such parameters and on the overall structural response is demonstrated.

● **6.12-9** Frick, T. M., **On simplified design methods for nonlinear dynamic mechanical systems,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 369-394.

Dimensional analysis and classical methods are combined to develop a simplified mathematical description of two practical nonlinear dynamic mechanical systems experiencing excitation similar to that caused by an earthquake. This method is used to obtain system descriptions in closed algebraic form with appropriate constants. The number of constants provides the designer with the minimum number of complex time history analyses or tests required to completely characterize the systems. Once these constants are evaluated, parametric and optimization studies can be performed very quickly by hand. Predictions based on application of the method are made. Comparisons of these predictions to results obtained from time history solutions show the method is a valuable design tool. Application of the method to other situations is briefly discussed.

● **6.12-10** Wu, S.-C. and Abel, J. F., **Representation and discretization of arbitrary surfaces for finite element shell analysis,** *International Journal for Numerical Methods in Engineering,* **14,** *6,* 1979, 813-836.

An interactive computer graphics system has been developed for generating the geometric description of an arbitrary shell surface. The various difficulties facing the user of sophisticated doubly-curved shell finite elements and the inefficiency of preprocessing for shell analysis are discussed to explain the benefits of this system. The method is a synthesis of spline theory and algorithms and is an interactive means for man-machine communication. The basic technique employed is a modified lofting method in which sectional curves are represented by a uniform B-spline, and the surface is interpolated between sections by cardinal splines. An inversion procedure is incorporated which increases significantly the efficiency of the B-spline approximation process. Static and dynamic graphic displays greatly enhance visualization at any stage of the procedure. Two examples of practical interest are presented in some detail to demonstrate the flexibility and usefulness of this approach. Some natural extensions of this system for interactive mesh generation on the surface are also demonstrated.

● **6.12-11** Jaeger, L. G. and Mufti, A. A., **Earthquake analysis of a nuclear power station turbine building,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 341-368.

This paper discusses the response spectrum approach to the seismic analysis of structures. The application of the method to the dynamic analysis of a nuclear power station turbine building is described, with the building represented by a 3-D finite element model. A method of representing a complex structure by a much simpler structure having the same dynamic characteristics of dominant modes is also presented. This method is said to be an economical alternative for the seismic analysis of complex structures.

● **6.12-12** Donea, J. and Laval, H., **An improved formulation of the parabolic isoparametric element for explicit transient analysis,** *Earthquake Engineering & Structural Dynamics,* **7,** *1,* Jan.-Feb. 1979, 23-29.

This paper illustrates the difficulties encountered in the use of standard, Galerkin-type, parabolic isoparametric elements for explicit transient analysis. These are associated with the mass lumping procedure as well as with incoherencies in the nodal loads induced by the element local field. To overcome these difficulties, it is suggested that the

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

parabolic element equations be formulated by a weighted residual method in which the weighting functions are the usual serendipity functions modified by an appropriate bubble-shape function. It is shown that such a formulation enables all the shortcomings of the Galerkin approach to be overcome. An example problem indicates the extent of improvement in results that can be obtained by the proposed method.

● **6.12-13** Chu, F. H. and Pilkey, W. D., **Transient analysis of structural members by the CSDT Riccati transfer matrix method,** *Computers & Structures,* **10,** *4,* Aug. 1979, 599–611.

A method for the direct integration of the dynamic governing partial differential equations of motion for structural members is developed. This technique is called the continuous-space discrete-time (CSDT) Riccati transfer matrix method. This formulation transforms a boundary value problem of governing partial differential equations of motion into a boundary value problem of ordinary differential equations. First, a standard procedure such as finite differences is employed to discretize the time derivatives. Then, a line solution technique such as the Riccati transfer matrix method is utilized to integrate the spatial derivatives. The stability and accuracy of the CSDT Riccati transfer matrix method using the Newmark generalized acceleration formulation for time discretization is studied. For a particular class of governing equations, it is shown that the method is unconditionally stable without amplitude decay error for particular parameter values in the Newmark formulation. The method, however, exhibits period elongation error as a function of the time step. Numerical results for bar and beam example problems indicate that this may well be a viable method for calculating the dynamic response of linear structural members.

● **6.12-14** Surana, K. S., **A general purpose free format input data system,** *Computers & Structures,* **10,** *4,* Aug. 1979, 583–597.

The free format input data system presented in this paper is designed and presented as an interface between the user and the parent program. The system converts a user's free format input data set into the fixed format data set of the parent program. Features of the system include data entries free of format specifications, appearance of leading, trailing and embedded blanks in a data line, horizontal repetition of data entries, vertical repetition of data entries, data group identification, comment data lines, tab settings, i.e., skipping to predetermined fields, elimination of group terminators, and teletype compatibility. The organization of the program is described in detail. Full notation, a sample example problem with input and program output, program listing with comment cards, and implementation details are also provided. This input system is an ideal "front end" for a general purpose finite element program. The system has been in use with the NISA finite element computer program since early 1976.

● **6.12-15** Durocher, L. L. and Gasper, A., **A versatile two-dimensional mesh generator with automatic bandwidth reduction,** *Computers & Structures,* **10,** *4,* Aug. 1979, 561–575.

A relatively straightforward mesh generation program based on isoparametric mapping concepts is presented. User-defined isoparametric superelements are subdivided, as specified by the user, into 3-noded or 6-noded triangular elements or into 4-noded or 8-noded isoparametric quadrilaterals. Temperatures and thicknesses (or any other characteristics) at the superelement nodes are mapped to provide the appropriate nodal values for the subelements. Material specification codes from parent superelements are also transferred as subelement characteristics. An automatic node renumbering scheme is included to minimize the nodal connectivity of the generated mesh.

● **6.12-16** Dendrou, B. A. and Houstis, E. N., **Uncertainty finite element dynamic analysis,** *Applied Mathematical Modelling,* 3, *2,* Apr. 1979, 143–150.

An inference-dynamic model is developed based on a model dynamic analysis using a moving boundary condition. The uncertainty of the physical parameters is implemented in the model using an inference scheme coupled with a perturbation technique. The first two statistical moments of the displacements and the stress field, estimated according to the proposed analytical scheme, are in good agreement with the initially assumed fields.

● **6.12-17** Collings, A. G. and Tee, G. J., **The solution of structural dynamics problems by the generalized Euler method,** *Computers & Structures,* **10,** *3,* June 1979, 505–515.

Stiff systems of second-order ordinary differential equations which describe the vibration of structures subject to dynamic loading may be solved by a variety of numerical algorithms. A one-parameter generalization of Euler's classical scheme for ordinary differential equations is investigated and shown to be applicable to such problems. The value of the parameter and the size of the timestep can be chosen on the basis of detailed analyses of the scheme. The Euler scheme is compared with Newmark's beta method. The application to nonlinear problems is indicated. As an example a three-story space frame, in the form of a triangular prism which is subjected to dynamic loading, is computed by several versions of the Euler scheme, and the results are compared with the exact solution. Complete ALGOL 60 procedures are included for applying the generalized Euler scheme to linear structural dynamics problems.

● *See **Preface**, page v, for availability of publications marked with dot.*

6.12-18 Ignaczak, J., **Domain of influence theorem in asymmetric elastodynamics**, *International Journal of Engineering Science*, **17**, *6*, 1979, 707-714.

A domain-of-influence theorem for the tensorial formulation of classical nonhomogeneous isotropic elastodynamics was established by the author in a previous paper. In this paper the author extends the results to the tensorial equations of asymmetric elastodynamics.

● **6.12-19** Herrera, I., **Theory of connectivity: a systematic formulation of boundary element methods**, *Applied Mathematical Modelling*, 3, *2*, Apr. 1979, 151-156.

A theory of connectivity recently developed by the author is applied to construct a systematic formulation of boundary element methods. The concept of complete connectivity condition is shown to supply an alternative to boundary integral equations. The general problem of connecting solutions defined in neighboring regions *R* and *E*, is shown to lead to complete connectivity conditions which permit the formulation of three kinds of variational principles; they involve, respectively, *R* union *E*, *R*, and the common boundary between *R* and *E* only.

6.12-20 Davies, J. M., **Multi-storey plane frames**, *Civil Engineering* [London], Apr. 1979, 64-69.

This paper presents a procedure for calculating the approximate elastic critical loads for plane frames and compares results calculated using alternative approximate methods with results calculated using the method described.

● **6.12-21** Barrett, K. E. and Demunshi, G., **Non-self-adjoint problems and essential boundary conditions**, *International Journal for Numerical Methods in Engineering*, **14**, *4*, 1979, 507-513.

In this paper it is shown how essential boundary conditions may be incorporated into variational principles for non-self-adjoint boundary value problems. Numerical results for a simple example of a second-order ordinary differential equation with a significant first derivative are obtained which are comparable in accuracy to those recently found by a Galerkin method using quadratic test and trial functions.

● **6.12-22** Recuero, A. and Gutierrez, J. P., **A direct linear system solver with small core requirements**, *International Journal for Numerical Methods in Engineering*, **14**, 5, 1979, 633-645.

This paper presents an algorithm and the corresponding FORTRAN IV program for solving a system of simultaneous equations of the type generated in structural analysis. Since it is based on the Gaussian elimination method, it is a direct method. However, it only needs to have in core as many equations as it can contain, with a minimum of two. The program offers the following advantages: (a) it takes into account zeros to avoid operations; (b) it considers very big numbers in the diagonal, corresponding to boundary conditions, to avoid operations; and (c) it can handle several load cases either simultaneously or in groups.

● **6.12-23** Basu, P. K. and Gould, P. L., **Finite element discretization of open-type axisymmetric elements**, *International Journal for Numerical Methods in Engineering*, **14**, *2*, 1979, 159-178.

A series of open-type elements which are compatible with axisymmetric thin shell elements are derived. These elements allow the effects of intermediate openings and discrete support systems for rotational shells to be realistically modelled in the dynamic regime. Consistent load vectors for several common cases are also derived. The availability of these elements in a public domain computer program enhances the possibility for modeling systems which are basically axisymmetric but which include intermediate or end supports using a rotational shell code.

● **6.12-24** Stern, M., **Families of consistent conforming elements with singular derivative fields**, *International Journal for Numerical Methods in Engineering*, **14**, *3*, 1979, 409-421.

Families of two- and three-dimensional finite elements are constructed for use in modeling fields with singular derivatives. The elements are complete over linear fields, conform with regular elements, and are easily programmed. A low-order exact quadrature rule is also derived for element stiffness calculations.

● **6.12-25** Hitchings, D. and Beresford, P. J., **A comparison of numerical methods for the aseismic design of mechanical systems**, *Engineering Design for Earthquake Environments*, Paper No. C183/78, 129-138. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The engineer is confronted with a variety of numerical techniques for calculating deformations and stresses induced by seismic loadings. In this paper, the three commonly used methods are compared and contrasted when applied to the seismic analysis of piping systems and the soil-structure interaction of nuclear reactors. The three methods are the time history specification of the support acceleration, response spectra specification of the supports, and stationary random movement of the supports. Guidelines based upon experience in using each of these techniques are presented. Included is a discussion of the interpretation and reliability of the results forecast by each type of analysis. The paper is illustrated with practical examples selected from analyses conducted by the authors.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

● **6.12-26** Beliveau, J.-G., **First order formulation of resonance testing,** *Journal of Sound and Vibration,* **65,** *3,* Aug. 8, 1979, 319–327.

An efficient formula for determining the matrix of frequency response functions is derived for the linear system of ordinary differential equations in structural dynamics having constant coefficients. The eigenvalues and eigenvectors of the system associated with the known mass, stiffness, and damping matrices are used without recourse to the inversion of complex matrices at each excitation frequency. The result may be applied to single- or multipoint excitation techniques, and the matrices need not be symmetric. The eigenvalues are assumed to occur in complex conjugate pairs with nonpositive real parts, and the Jordan canonical form of the system matrix is presumed to be diagonal. Expressions are given for the sensitivity of the response, and an example of an eight-story building is used to demonstrate the computational efficiency of the formula.

● **6.12-27** Everstine, G. C., **A comparison of three resequencing algorithms for the reduction of matrix profile and wavefront,** *International Journal for Numerical Methods in Engineering,* **14,** *6,* 1979, 837–853.

Three widely used nodal resequencing algorithms were tested and compared for their ability to reduce matrix profile and root-mean-square (rms) wavefront, the latter being the most critical parameter in determining matrix decomposition time in the NASTRAN finite element computer program. The three algorithms are Cuthill-McKee (CM), Gibbs-Poole-Stockmeyer (GPS), and Levy. Results are presented for a diversified collection of 30 test problems ranging in size from 59 to 2680 nodes. It is concluded that GPS is exceptionally fast, and, for the conditions under which the test was made, best able to reduce profile and rms wavefront consistently. An extensive bibliography of resequencing algorithms is included.

● **6.12-28** Lukkunaprasit, P. and Kelly, J. M., **Dynamic plastic analysis using stress resultant finite element formulation,** *International Journal of Solids and Structures,* **15,** *3,* 1979, 221–240.

A stress-resultant finite element formulation is developed for the dynamic plastic analysis of plates and shells of revolution undergoing moderate deformation. A nonlinear elastic-viscoplastic constitutive relation simulates the behavior of rate-sensitive and rate-insensitive materials. A local time-step subdivision procedure is developed to stabilize the direct numerical integration of the system of nonlinear dynamic equations; satisfactory accuracy is obtained with large time steps. The simple nonlinear viscoplastic constitutive model approximates the nonlinear dynamic behavior of metals over a wide range of strain rates and has the advantage that the need to identify the state of the material during deformation is eliminated and the numerical algorithm thereby simplified. Direct step-by-step integration techniques are used to solve the system of equations governing the motion of a structure under dynamic loading. An implicit Runge-Kutta scheme in conjunction with a Newton-Raphson iteration technique is used in solving systems of first-order ordinary differential equations.

● **6.12-29** Spanos, P.-T. D. and Iwan, W. D., **Harmonic analysis of dynamic systems with nonsymmetric nonlinearities,** *Journal of Dynamic Systems, Measurement, and Control, ASME,* **101,** *1,* Mar. 1979, 31–36.

The generalized method of equivalent linearization is modified to be applicable for multidegree-of-freedom dynamic systems with nonsymmetric nonlinearities subjected to harmonic monofrequency excitation. Readily applicable formulas are given for the construction of the equivalent linear systems related to a class of systems commonly encountered in engineering applications.

● **6.12-30** Rose, D. J. et al., **Algorithms and software for in-core factorization of sparse symmetric positive definite matrices,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 411–418. (For a full bibliographic citation, see Abstract No. 1.2-4.)

This paper is concerned with the in-core solution by Gaussian elimination of the system of linear equations $Ax = b$ where A is an N by N symmetric, positive definite, sparse matrix and x and b are vectors of length N. Such systems occur throughout structural analysis and scientific computation, and often their solution comprises the bulk of the work required for the numeric calculations in which they arise. This paper surveys the current state-of-the-art in algorithms for the solution of systems like the equation above and points to areas which need further work.

● **6.12-31** Golden, M. E., **Geometric structural modelling: a promising basis for finite element analysis,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 347–350. (For a full bibliographic citation, see Abstract No. 1.2-4.)

The desirable features of the geometric language GPRIME are discussed. GPRIME is an interactive graphics language for structural modeling which employs the cubic B-spline function as the single internal data representation for all curves and surfaces. The development and implementation of the language are described in conjunction with illustrations of computer-drawn graphic output. Future development of GPRIME is discussed.

● **6.12-32** Park, S. and Washam, C. J., **Drag method as a finite element mesh generation scheme,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 343–346. (For a full bibliographic citation, see Abstract No. 1.2-4.)

The "drag mesh" method for automatic generation of finite elements is presented. Highlights of the technique are that it offers: (1) simple, efficient element and node generation in regions of a structural model where a similarity of cross section is maintained; (2) exact model coordinate computation for surfaces and volumes of revolution and for many other doubly curved regions; (3) flexible user control of element and node numbering; and (4) simultaneous generation of 1-, 2-, and 3-dimensional finite elements.

● **6.12-33** Peano, A. et al., **Adaptive approximations in finite element structural analysis,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 333-342. (For a full bibliographic citation, see Abstract No. 1.2-4.)

Adaptive computer programs are expected to control the discretization error by increasing the number of degrees-of-freedom in regions where the initial finite element model is not adequate. This automated convergence process is monitored by convenient local error criteria. There are three advantages. First, the number of finite elements is determined by the geometry rather than the requirements of precision. In many cases, a dramatic reduction of the data preparation effort is possible. Second, the procedure itself validates the finite element model. The analyst's task is considerably simplified. Third, the minimum number of degrees-of-freedom may be used to get the desired level of precision. A computational scheme which allows for efficient reanalysis has been recently implemented. New degrees-of-freedom are defined by introducing higher order displacement modes on the same grid. The improved stiffness matrix contains the previous stiffness matrix as a submatrix and the numerical effort expended in triangularizing the previous stiffness matrix can be saved. The new approach is demonstrated by applications to two- and three-dimensional elasticity, including singularity problems.

● **6.12-34** Gould, P. L., **Condensation for mixed dynamic FE analysis of rotational shells,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 251-253. (For a full bibliographic citation, see Abstract No. 1.2-4.)

Mixed method finite elements are characterized by a set of explicit nodal variables which are composed of both stress and displacement terms. In the static regime such elements are generally derived from Reissner's variational principle. In this paper, a dynamic counterpart to the static rotational shell element is derived. A notable feature of the static element is the capacity for describing the shell response with relatively few nodal variables. This is achieved primarily through the use of high-order interpolation functions and static condensation. The mere extension of this approach to dynamic problems, however, presents some fundamental difficulties since the analogous kinematic condensation is not exact. Although computational results are not included in this paper, it is anticipated that kinematic condensation may also be effectively used for mixed method models. Moreover, it will be shown that for the mixed method formulation the overall condensation as proposed by Karnopp may be decomposed into kinematic and static components thereby separating the approximate and exact operations and maintaining the parallel with the static procedure insofar as feasible.

● **6.12-35** Talaslidis, D. and Wunderlich, W., **Static and dynamic analysis of Kirchhoff shells based on a mixed finite element formulation,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 239-249. (For a full bibliographic citation, see Abstract No. 1.2-4.)

Mixed curved shell elements are presented for the static and free vibration analyses of arbitrary Kirchhoff shells. Following derivation of the appropriate generalized linear element matrix and the consistent mass matrix, the paper discusses the properties of mixed models when applied to static and dynamic analyses of Kirchoff shells. An outline of solution algorithms which take into consideration the special properties of generalized variational principles is given. Several numerical plate and shell examples demonstrate the applicability of the method.

● **6.12-36** Wright, J. P., **Mixed time integration schemes,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 235-238. (For a full bibliographic citation, see Abstract No. 1.2-4.)

A current topic of research is the development of structural dynamics codes which permit different time integration methods to be used in different parts of a structure. The primary goal of this effort is the design and implementation of more efficient solution procedures. This paper presents a review of this research and emphasizes factors important in this work. In particular, it is shown that operator splitting methods provide a natural framework for the future development of consistent and stable mixed integration schemes.

● **6.12-37** Alizadeh, A. and Will, G. T., **A substructured frontal solver and its application to localized material nonlinearity,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 225-231. (For a full bibliographic citation, see Abstract No. 1.2-4.)

An equation solver is developed based on the Gaussian elimination scheme. The in-core space requirement is minimized by implementing three levels of partitioning of the degrees-of-freedom. The solver is further developed to analyze materially nonlinear structures with localized plastic regions. The method proves efficient for the solution of large structural systems in computing environments with severe in-core space limitations.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.12-38** Frey, A. E., Hall, C. A. and Porsching, T. A., **An application of computer graphics to three dimensional finite element analyses,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 149-154. (For a full bibliographic citation, see Abstract No. 1.2-4.)

The interactive computer program PLANIT is described which is useful in detecting anomalies in a finite element idealization of a three-dimensional structure. Intersections of a sequence of planes with a catenation of brick elements are constructed and scanned with the aid of a graphics terminal.

● **6.12-39** Foley, J. D., **A standard computer graphics subroutine package,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 141-147. (For a full bibliographic citation, see Abstract No. 1.2-4.)

The advantages and disadvantages of computer graphics standards are discussed and several possible types of standards are described. The capabilities of a proposed basic standard, the ACM/SIGGRAPH Core System, are presented. An implementation of the Core System and several relevant design issues are outlined.

● **6.12-40** Korncoff, A. R. and Fenves, S. J., **Symbolic generation of finite element stiffness matrices,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 119-124. (For a full bibliographic citation, see Abstract No. 1.2-4.)

A symbolic processor is presented which can assist in the generation of stiffness matrices for finite elements based on a recently developed symbolic language. Operations are performed upon the element characteristics and material properties in symbolic form to produce a "matrix template" consisting of the algebraic expressions for the stiffness matrix coefficients as functions of the problem parameters in literal form. Required input is minimized by automatically synthesizing the constituent matrices from user-supplied specifications of displacement functions, material properties, and stress-strain relationships, all in symbolic notation. Elements of the computational implementation and an example are presented which illustrate the procedures adopted and the symbolic processing facilities used. The results of the research presented are extrapolated to suggest directions for future research in the specific area of finite element analysis and in general areas of application of symbolic processing.

● **6.12-41** Noor, A. K. and Andersen, C. M., **Computerized symbolic manipulation in structural mechanics-progress and potential,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 95-118. (For a full bibliographic citation, see Abstract No. 1.2-4.)

This paper summarizes the status and recent applications of computerized symbolic manipulation to structural mechanics problems. The applications discussed include: (1) generation of characteristic arrays of finite elements; (2) evaluation of effective stiffness and mass coefficients of continuum models for repetitive lattice structures; and (3) application of the Rayleigh-Ritz technique to the free vibration analysis of laminated composite elliptic plates. The major advantages of using computerized symbolic manipulation in each of these applications are outlined. A number of problems which limit the realization of the full potential of computerized symbolic manipulation in structural mechanics are examined and some of the means of overcoming them are discussed.

● **6.12-42** Jordan, H. F. and Sawyer, P. L., **A multimicroprocessor system for finite element structural analysis,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 21-29. (For a full bibliographic citation, see Abstract No. 1.2-4.)

This paper discusses the architecture of a prototype "finite element machine" currently being built.

● **6.12-43** Noor, A. K. and Lambiotte, Jr., J. J., **Finite element dynamic analysis on CDC STAR-100 computer,** *Computers & Structures,* **10,** *1/2,* Apr. 1979, 7-19. (For a full bibliographic citation, see Abstract No. 1.2-4.)

Computational algorithms are presented for the finite element dynamic analysis of structures on the CDC STAR-100 computer. The spatial behavior is described using higher order finite elements. The temporal behavior is approximated by using either the central difference explicit scheme or Newmark's implicit scheme. In each case, the analysis is broken up into a number of basic macro-operations. Discussion is focused on the organization of the computation and the mode of storage of different arrays to take advantage of the STAR pipeline capability. The potential of the proposed algorithms is discussed and CPU times are given for performing the different macro-operations for a shell modeled by higher order composite shallow shell elements having 80 degrees-of-freedom.

● **6.12-44** Hudspeth, R. T. and Borgman, L. E., **Efficient FFT simulation of digital time sequences,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM2,* Proc. Paper 14517, Apr. 1979, 223-235.

A stacked, inverse, finite Fourier transform (FFT) algorithm is presented that will efficiently synthesize a discrete random time sequence of N values from only N/2 complex values having a desired known spectral representation. This stacked inverse FFT algorithm is compatible with the synthesis of discrete random time sequences that are used with the more desirable periodic-random type dynamic testing systems used to compute complex-valued transfer functions by the frequency-sweep method.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● 6.12-45 McVerry, G. H., Beck, J. L. and Jennings, P. C., **Identification of linear structural models from earthquake records**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 515–524.

Two techniques for identifying linear structural models are successfully applied to earthquake records obtained from multistory buildings. The methods yield the optimal modal parameters for either the entire response, or portions of the response. By using the latter approach, equivalent linear parameters for amplitude levels up to the onset of significant damage can be obtained. Results for specific buildings are given.

● 6.12-46 Subramanian, R. and Krishnan, A., **Non-linear discrete time systems analysis by multiple time perturbation techniques**, *Journal of Sound and Vibration*, 63, *3*, Apr. 8, 1979, 325–335.

This paper presents the application of the two-variable expansion method for the study of a class of nonlinear difference equations arising in discrete time systems. The two-variable expansion method, a multi-time perturbational technique which has been used to a considerable extent for the analysis of nonlinear differential equations, is used for the investigation of the response characteristics of nonlinear difference equations. Examples are provided to illustrate the theoretical framework.

● 6.12-47 Collings, A. G. and Tee, G. J., **Stability and accuracy of the generalized Euler method for ordinary differential equations, with references to structural dynamics problems**, *Engineering Structures*, **1**, *2*, Jan. 1979, 99–108.

The stability and accuracy of the generalized Euler method for the numerical solution of initial-value problems for ordinary differential equations are analyzed in detail. A justification is given for the application of extrapolation techniques to the Euler results computed with different step sizes for nonlinear (and linear) ordinary differential equations. High-frequency components (and/or heavily damped components) in the analytic solution produce alternating oscillatory components in the Euler solution, which decay very slowly when the Euler parameter equals 1/2. As an example, the vibration of a three-story space frame in the form of a triangular prism is computed by the generalized Euler method, and this "ringing" effect is detected.

● 6.12-48 Krings, W. and Waller, H., **Contribution to the numerical treatment of partial differential equations with the Laplace transformation-an application of the algorithm of the fast Fourier transformation**, *International Journal for Numerical Methods in Engineering*, **14**, *8*, 1979, 1183–1196.

The main advantage of the Laplace transformation is its use in converting a differential equation into an algebraic equation. This method has proved to be especially effective in connection with ordinary differential equations, namely, those with only one independent variable. For analytic computations, tables are used for the inverse Laplace transformation. When such a procedure is no longer possible, it is often difficult to find solutions with the aid of residual calculations. Frequently, one has to consider the space coordinates x, y and z, besides the time t, as four independent variables. When two independent variables, for example, x and t, are given, a partial differential equation is transformed into an ordinary one. Even when the solution of the latter can be found, the inverse Laplace transformation usually cannot be solved analytically because the functions to be transformed are too complicated. In the case of more than one space coordinate, the methods of difference—differential equations—or of finite elements can be used. Numerical calculations of integral transformations are not as popular as other methods for solving differential equations, e.g., direct numerical integration.

Because the authors have successfully treated ordinary differential equations with integral transformations, it may be seen in this paper how partial differential equations can be solved numerically with the method of Laplace transformation using the algorithm of the fast Fourier transformation. A suitable method for the integration of linear partial differential equations with two independent variables x and t can be established.

● 6.12-49 Leung, Y.-T., **An accurate method of dynamic substructuring with simplified computation**, *International Journal for Numerical Methods in Engineering*, **14**, *8*, 1979, 1241–1256.

A new dynamic substructuring method is presented. The substructures are identified by their fixed-interface modes and the condensed stiffness and mass matrices at zero vibration frequency. Physical coordinates are used instead of the modal coordinates to make the condition of compatibility between elements applicable. The dimension of the fundamental matrices is equal to the number of interface coordinates for each substructure. All information needed to formulate the fundamental matrices may be obtained experimentally. Both discrete and continuous parameter models are considered. A number of numerical examples are given, and the method is compared with other dynamic substructuring methods. It is shown that the numerical accuracy lost in the ordinary eigenvalue economization process may be recovered by the present method.

● 6.12-50 Bathe, K.-J. and Bolourchi, S., **Large displacement analysis of three-dimensional beam structures**, *International Journal for Numerical Methods in Engineering*, **14**, *7*, 1979, 961–986.

● *See **Preface**, page v, for availability of publications marked with dot.*

An updated Lagrangian formulation and a total Lagrangian formulation of a three-dimensional beam element are presented for large displacement and large rotation analysis. It is shown that the two formulations yield identical element stiffness matrices and nodal point force vectors, and that the updated Lagrangian formulation is computationally more effective. The formulation has been implemented, and the results of some sample analyses are given.

● **6.12-51** Vugts, J. H. and Hayes, D. J., **Dynamic analysis of fixed offshore structures: a review of some basic aspects of the problem,** *Engineering Structures,* **1**, *3,* Apr. 1979, 114-120.

The current trends of increasing the operating depth for fixed offshore structures and the attendant increase in natural period(s) point to the need for realistic dynamic analysis as an integral part of the design process. Such analysis is required not only for estimating structural response to extreme (design) storms or earthquakes but also for estimating response to less severe but frequently occurring sea states. This latter aspect may, in fact, be the more restrictive consideration, since it is the response to these loadings which controls the fatigue life of the structural components. By focusing on the fatigue aspect, it becomes immediately apparent that an accurate and detailed analysis is required if the analysis is to be of practical use.

The dynamic analysis of offshore structures has received increasing attention. Most work has been directed to highlighting certain aspects of the problem or techniques. This paper addresses the broader issue of defining the basic problem areas, the degree of uncertainty about certain aspects, and the alternative analytical tools that can be used to achieve a practical solution in the design process.

A realistic dynamic analysis of a fixed offshore structure is a complex undertaking. The problem is that of a multidegree-of-freedom mechanical system, and, in most cases, it is essentially of a three-dimensional nature. The loading by waves is random, both spatially and timewise. The boundary conditions are usually represented by springs and dashpots, the characteristics of which are governed by the foundation-soil interaction. These springs and dashpots are complex in themselves and usually have a profound influence on the dynamics. Damping is small and of great importance. Neither its precise magnitude nor its spatial distribution is known. The problems associated with an adequate formulation of the dynamic problem are aggravated by the limited knowledge of subjects such as wave loading on structures and soil mechanics.

The results of preliminary investigations indicate that simplifications based on the apparent reasonable neglect of certain aspects may lead to highly erroneous results. Approximations analogous to the well-known and well-understood properties of the single degree-of-freedom system are rarely adequate. Therefore, a full and comprehensive dynamic analysis appears to be the only satisfactory way of dealing with the problem. In this paper, the following general aspects of the problem are briefly discussed: (1) time domain vs. frequency domain description; (2) modal superposition vs. direct integration in physical coordinates (usually in conjunction with a finite element description); and (3) damping.

● **6.12-52** Arvidsson, K., **Interaction between coupled shear walls and frames,** *Proceedings, The Institution of Civil Engineers,* Part 2, **67**, Paper 8174, Sept. 1979, 589-596.

A method is presented for the analysis of interacting coupled shear walls and frames. The analysis is based on the continuous connection technique, whereby the high degree of static indeterminability in a shear wall-frame system is reduced to an easily solved differential equation. Secondary design effects, such as column shortening in the frame and elastic foundation conditions, are also taken into account. Two examples for a uniformly distributed load show a significant deviation from earlier results. A comparison with computer calculations for a discrete frame confirms the accuracy of the proposed method.

● **6.12-53** Vanderbilt, M. D., **Equivalent frame analysis for lateral loads,** *Journal of the Structural Division, ASCE,* **105**, *ST10,* Proc. Paper 14931, Oct. 1979, 1981-1998.

The equivalent frame method for analyzing reinforced concrete buildings described in the ACI Building Code Requirements (ACI 318-77) is suitable for analyzing single stories for gravity loading only. A new procedure that permits using the equivalent frame concepts for the analysis of multistory buildings for both lateral and gravity loads is described. Limited verification studies show the method predicts lateral deflections that generally agree with measured deflections. Comparisons of the new analytical procedure with conventional plane frame analyses made using effective slab widths are given. Problems and limitations in applying the method in plane frame and space frame analyses are reviewed.

● **6.12-54** Neubert, V. H. and Rangaiah, V. P., **A note on the lumped parameter beam models based on mechanical impedance,** *Journal of Sound and Vibration,* **64**, *3,* June 8, 1979, 379-385.

Investigation of the three-parameter lumped mass model for a Bernoulli-Euler clamped-clamped beam has shown that the model is a universal model with respect to simple boundary conditions. Numerical results for the transient response caused by a low-frequency ground shock demonstrate the superiority of the beam model based on impedance methods.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.12-55** Morrone, A., **Analysis of seismic testing motions with instantaneous response spectra,** *Nuclear Engineering and Design,* **51,** *3,* Feb. 1979, 445-451.

Synthetic multiple-frequency and single-frequency motions are analyzed for the adequacy of the motions to simulate a calculated seismic motion for seismic testing of nuclear power plant equipment. The analysis is performed by first comparing the time-independent response spectra of the motions and then by comparing response spectra derived at an instant of time, that is, instantaneous response spectra. The results show that, even though the time-independent response spectrum of the calculated motion is fully enveloped by that of a synthetic test motion, full enveloping is never obtained with the actual responses at any given time. Recommendations are given for practical test methods and the type of test motions.

● **6.12-56** Leimbach, K. R. and Schmid, H., **Automated analysis of multiple-support excitation piping problems,** *Nuclear Engineering and Design,* **51,** *2,* Jan. 1979, 245-252.

An automated solution algorithm is presented for the treatment of multiple-support excitation piping problems. The method is an extension of the well-known response spectrum analysis method which is routinely used for seismic analysis of structural systems. The new algorithm was incorporated in the Kraftwerk Union proprietary computer code KWUROHR for static and dynamic analysis of piping systems. In this paper, the numerical results from the use of envelope and multiple-support acceleration input spectra are presented for two typical piping systems in nuclear power plants. From a comparison of these results, it becomes clear that the multiple-support excitation method should be recommended as the standard analysis procedure for systems attached to support points which are subjected to different acceleration spectra. The additional computer cost is negligible.

● **6.12-57** Anderson, J. G. and Trifunac, M. D., **A note on probabilistic computation of earthquake response spectrum amplitudes,** *Nuclear Engineering and Design,* **51,** *2,* Jan. 1979, 285-294.

This paper analyzes a method for the computation of the pseudo-relative velocity spectrum and the absolute acceleration spectrum so that the amplitudes and the shapes of these spectra reflect the geometrical characteristics of the seismic environment of the site. The estimated spectra also incorporate the geologic characteristics at the site, the direction of ground motion, and the probability of exceeding a specified motion. An example of applying this method in a realistic setting is presented, and the uncertainties of the results are discussed.

6.12-58 Broucke, R., **On the construction of a dynamical system from a preassigned family of solutions,** *International Journal of Engineering Science,* **17,** *11,* 1979, 1151-1162.

This article treats the determination of the forces in a dynamic system when the general form of the solution is given. Such a determination makes it possible to construct a system with a predetermined type of behavior. It is shown that the problem generally requires the solution of a partial differential equation. The method of constraints and Lagrange multipliers are used to derive this equation. The relation with some past results (Dainelli's formulas) is shown. As an illustration of the application of the method, the partial differential equation is solved for a family of potentials that results in oscillatory motions on a parabolic curve. A simple integrable system is first constructed, generalizing free-fall motion on a parabolic path. A more complex solution of the partial differential equation is then used to construct a fairly complex dynamic system with two degrees-of-freedom. This system has been studied in some detail with numerical methods. In particular, the periodic oscillations of the system are classified and their characteristic exponents and bifurcations are studied.

● **6.12-59** Budcharoentong, D. and Neubert, V. H., **Finite elements and convergence for dynamic analysis of beams,** *Computers & Structures,* **10,** 5, Oct. 1979, 723-729.

Two methods are considered for improving the accuracy of finite elements for calculation of the dynamic response of the Bernoulli-Euler beam. One method involves a generalized-coordinate procedure in which quadratic displacement functions are used to formulate a nonconsistent mass matrix. In the second approach, a lumped-parameter model is developed by making the dynamic stiffness, or mechanical impedance, accurate at the connection points. The two finite elements developed are compared with the consistent mass model and a center-of-gravity lumped mass model. Of particular interest is the rate of convergence of natural frequencies and dynamic stiffness.

● **6.12-60** Smith, H. W., **Finite element costs,** *Computers & Structures,* **10,** 5, Oct. 1979, 717-721.

This paper describes an extension to the classical finite element analysis methods. Using the same data inherent in the stiffness matrix, and adding cost parameters as input, a finite element structural analysis program is shown to provide cost data output. The basic concept is that the material costs are only a fraction of the total costs, which include labor and overhead. It is theorized that the labor and overhead costs may be dominant, and are related to structural complexity and numbers of joints. Two examples are given: a simple four-member truss and a transmission tower.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.12-61** Prathap, G., **On the Berger approximation: a critical re-examination,** *Journal of Sound and Vibration,* **66,** *2,* Sept. 22, 1979, 149–154.

The Berger approximation has been invoked by many authors in spite of the fact that no rational mechanical basis for the approximation can be found. Many recent papers have raised doubts on its applicability. In this paper, certain well-known results from the two-dimensional theory of elasticity are used to suggest a plausible explanation for the origin of the Berger method. The arguments can be developed further to show that other specious Berger-like approximations can be developed, all of them leading to uncoupled nonlinear equations yielding different overall results. Further, it is shown that such methods fail to predict the nonlinear behavior with respect to important parameters and that whatever accuracy is obtained in the solution of a particular problem can probably be attributed to fortuity.

● **6.12-62** Chander, S., Donaldson, B. K. and Negm, H. M., **Improved extended field method numerical results,** *Journal of Sound and Vibration,* **66,** *1,* Sept. 8, 1979, 39–51.

This paper considers an approximate method of analysis for boundary value problems called the extended field method. The purpose of the paper is to present a series of numerical results which (1) supersedes all previously reported unsatisfactory numerical results and (2) extends the geometric range of application. The extended field method can now produce, for all types of harmonically vibrating, uniform, thin plates, deflection amplitude numerical solutions of unsurpassed convergence.

● **6.12-63** Chander, S. and Donaldson, B. K., **Extended field method free vibration solutions,** *Journal of Sound and Vibration,* **66,** *1,* Sept. 8, 1979, 53–62.

An apparent paradox involving the relation between the plate-bending natural frequencies of two elastic plates when one plate encloses the other is examined and dispelled. Specifically it is shown (1) that the extended field method of analysis can calculate exactly, or with excellent numerical convergence, plate bending eigenvalues, and (2) that the extended field method forced vibration solutions are not compromised by the singularities at the eigenvalues of the extended plate.

● **6.12-64** Goto, H. and Hangai, Y., **Comparison of five approximate methods of the nonlinear equation of motion,** *Bulletin of Earthquake Resistant Structure Research Center,* **12,** Mar. 1979, 43–55.

It is often difficult to select the most suitable method for the analysis of nonlinear equations of motion. In this paper, the properties of several approximate methods are analyzed. The results of the first- and second-order approximations of each method are presented for a single degree-of-freedom system containing quadratic and cubic terms. Differences between each method are discussed.

● **6.12-65** Monro, D. M., **Interpolation by fast Fourier and Chebyshev transforms,** *International Journal for Numerical Methods in Engineering,* **14,** *11,* 1979, 1679–1692.

Transform methods for the interpolation of regularly spaced data are described. The methods are based on fast evaluation using discrete Fourier transforms. For periodic data adequately sampled, the fast Fourier transform (FFT) is used directly. With undersampled or aperiodic data, a Chebyshev interpolating polynomial is evaluated by means of the FFT to provide minimum deviation and distributed ripple. The merits of two kinds of Chebyshev series are compared. All the methods described produce an interpolation passing directly through the given values and are applied easily to the multidimensional case.

● **6.12-66** Simpson, R. B., **Automatic local refinement for irregular rectangular meshes,** *International Journal for Numerical Methods in Engineering,* **14,** *11,* 1979, 1665–1678.

The use of local mesh refinements for the generation of meshes for the finite element or finite difference methods is studied. A class of rectangular meshes which admit restricted local refinements, referred to as irregular rectangular meshes, is introduced and its representation discussed. Properties of algorithms for mesh refinements are discussed from the viewpoints of termination with a mesh in the specified class, memory utilization, symmetry, and fragmentation of the mesh.

● **6.12-67** Matthies, H. and Strang, G., **The solution of nonlinear finite element equations,** *International Journal for Numerical Methods in Engineering,* **14,** *11,* 1979, 1613–1626.

An algorithm is described which appears to give an efficient solution of nonlinear finite element equations. The algorithm, which is a quasi-Newton method, is compared with some of the alternatives. Initial tests of its application to both material and geometric nonlinearities are discussed.

● **6.12-68** Seyranian, A. P., **Homogeneous functionals and structural optimization problems,** *International Journal of Solids and Structures,* **15,** *10,* 1979, 749–759.

Extremal problems with homogeneous functionals with one or several constraints are investigated. On the basis of general properties of the optimal and quasi-optimal solutions of these problems, optimization problems of elastic structures are considered and discussed.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.12-69** Popov, E. P., Le, D. Q. and Petersson, H., **Program SUBWALL: finite element analysis of structural walls,** *Journal of the American Concrete Institute,* **76,** *6,* Title No. 76-30, June 1979, 679–696.

This paper introduces an efficient and refined special purpose finite element computer program, SUBWALL, for linear elastic structural analysis and design of complex reinforced concrete walls under arbitrary in-plane static loadings. An application of the substructuring technique as a means of reducing computer costs and increasing versatility in the use of finite elements for analyzing very large and complex structural walls is emphasized. Two detailed numerical examples are presented to illustrate the usefulness of the program in a design office.

● **6.12-70** Jain, A. K. and Goel, S. C., **Hysteresis models for steel members subjected to cyclic buckling or cyclic end moments and buckling (user's guide for DRAIN-2D: EL9 and EL10),** *UMEE 78R6,* Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Dec. 1978, 98.

Elements EL9 and EL10 are general purpose programs for the analysis of steel members subjected to cyclic buckling and cyclic end-moment-buckling, respectively. These elements are developed for use with the DRAIN-2D computer program. This manual describes the essential features of these two new elements and provides their FORTRAN listings. The development of an axial load-axial displacement hysteresis model as used for these elements has been described in a previous report.

● **6.12-71** Sackman, J. L. and Kelly, J. M., **Seismic analysis of internal equipment and components in structures,** *Engineering Structures,* **1,** *4,* July 1979, 179–190.

An analytical method is developed whereby a simple estimate can be obtained of the maximum dynamic response of light equipment attached to a structure subjected to ground motion. The natural frequency of the equipment, modeled as a single degree-of-freedom system, is considered to be close or equal to one of the natural frequencies of the N degree-of-freedom structure. This estimate provides a convenient, rational basis for the structural design of the equipment and its installation. The approach is based on the transient analysis of lightly damped tuned or slightly detuned equipment-structure systems in which the mass of the equipment is much smaller than that of the structure. It is assumed that among the information available to the designer are a design spectrum for the ground motion, fixed-base modal properties of the structure, and fixed-base properties of the equipment. The results obtained are simple estimates of the maximum acceleration and displacement of the equipment. The method can also be used to treat closely spaced modes in structural systems, where the square root of the sum of squares procedure is known to be invalid. This analytical method is also applied to untuned equipment-structure systems for which the conventional floor spectrum method is mathematically valid. A closed-form solution is obtained which permits an estimate of the maximum equipment response to be obtained without the necessity of computing time histories, as required by the conventional floor spectrum method.

● **6.12-72** Abdelrahman, A. M., Yun, C. B. and Wang, P. C., **Subcritical excitation and dynamic response of structures in frequency domain,** *Computers & Structures,* **10,** *5,* Oct. 1979, 761–771.

The main objective of this paper is to explore the idea of the critical and subcritical excitations for the assessment and prediction of the earthquake resistance of structures using the frequency domain method. A technique for the least-square fitting of complex valued functions to obtain the subcritical excitation is also developed in this paper. Results obtained in this study appear to be consistent with those obtained in the time domain method. However, the frequency domain method is more efficient in performing the analysis and requires less computing time.

● **6.12-73** Radhakrishnan, N. et al., **List of computer programs for computer-aided structural engineering,** *Technical Report K-78-1,* Automatic Data Processing Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Feb. 1978, 117. (NTIS Accession No. AD/A-052 789)

This report contains a list of computer programs related to structures and to structural engineering that are available from the U.S. Army Corps of Engineers. The list is arranged according to structural type and includes the name and number of the computer program, the author or supplier, the library holding the program (if applicable), the computer and mode of the program, information about documentation, and a short description of the main objective of the program. There are twenty-two structural groupings; programs pertaining to more than one subject category are cross-listed.

● **6.12-74** Williams, F. W., **Symmetric sub-structures,** *Computers & Structures,* **10,** *5,* Oct. 1979, 797–804.

The method presented in this paper applies to substructures when the stiffness matrix method is used, and the substructures have a single plane of symmetry or two or three mutually perpendicular planes of symmetry. The symmetry is used to reduce the computation time. The method can be used when there are several levels of substructure, and applies to any symmetric substructure even if the substructures which it contains, or by which it is itself contained, are not symmetric. The difficulty of assessing the importance of the computational savings which can be made by using the symmetry of substructures is discussed. A simple but rather crude measure of these savings has been adopted and applied to eleven examples. The examples cover a wide range of structural problems, either directly or by extrapolation, and show that substantial computational savings can often be obtained.

● **6.12-75** Bareau, H., **Convenient representation method for spatial finite element structures,** *Computers & Structures,* **10,** 5, Oct. 1979, 815–819.

A calculation procedure is presented in this paper which allows the visible and invisible lines of spatial structures to be differentiated.

● **6.12-76** Hansteen, O. E. and Bell, K., **On the accuracy of mode superposition analysis in structural dynamics,** *Earthquake Engineering & Structural Dynamics,* **7,** 5, Sept.-Oct. 1979, 405–411.

It is pointed out in this paper that the number of modes which should be included in a mode superposition dynamic response analysis depends on both the frequency content and the distribution of the loading. If the loading frequency is low, the effect of the higher modes can be approximated by a static analysis. A technique is described for calculating the static contribution from the higher modes; the total response is then represented by the sum of the lower mode dynamic response and the higher mode static effects. The effectiveness of the procedure is demonstrated by a numerical example.

● **6.12-77** Teal, E. J., **Approximate seismic dynamic design based on basic first mode shapes,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 58, 21.

This paper develops the modal dynamic response factors for the basic deflected shapes which buildings tend to assume when subjected to seismic lateral loads. The factors are first developed for each of the first four mode shapes related to a basic fundamental mode shape. Factors are then developed for the related response of a family of modes using single degree-of-freedom spectral curves for typical ground motions. With these factors, a close estimate of the combined modal dynamic response of a typical building to a typical ground motion can be quickly obtained and the relation between single degree-of-freedom and multidegree-of-freedom response is better understood.

● **6.12-78** Ferrante, A. J., de Lima, E. P. and Ebecken, N., **Problem oriented languages for finite element analysis,** *Applied Numerical Modelling,* Proceedings of the 2nd International Conference held at Madrid Polytechnic Univ., Spain, Sept. 1978, Pentech Press, London, 1979, 635–648.

● **6.12-79** Rosman, R., **Solution of a building structures boundary-value problem,** *Applied Numerical Modelling,* Proceedings of the 2nd International Conference held at Madrid Polytechnic Univ., Spain, Sept. 1978, Pentech Press, London, 1979, 479–486.

The mechanical behavior of a frequent type of structure is simulated by a continuous model. The corresponding boundary-value problem is formulated by a second-order linear matrix differential equation and a linear matrix algebraic equation, both being coupled. An appropriate formulation is possible by use of the stationary-functional principle. A two-step numerical solution is developed for the boundary-value problem. In the first step, the type 1 redundants are eliminated, so that a coupled set of the type 2 redundants is left. In the second step, the coupled equations are decoupled. This is done by a nonsingular, linear transformation using the properties of the eigenvalues and eigenvectors of the matrices. The solution of the decoupled equations is already known. The algorithm, developed for a structural mechanics application, is expected to be of use in other engineering science fields.

● **6.12-80** Cundall, P. A. et al., **Solution of infinite dynamic problems by finite modelling in the time domain,** *Applied Numerical Modelling,* Proceedings of the 2nd International Conference held at Madrid Polytechnic Univ., Spain, Sept. 1978, Pentech Press, London, 1979, 339–351.

The purpose of this paper is to present a practical solution to the boundary reflection problem generally encountered in numerical modeling of infinite media. From published literature on the subject, it appears that the nonreflecting boundary problem can be solved exactly using a numerical procedure that works in the frequency domain. However, with the growing acceptance and applicability of nonlinear explicit time domain solutions, there is a great need for a nonreflecting boundary which works in the time domain and transmits complex waves at all angles of incidence. The method presented in this paper solves this problem by advancing and refining the ideas presented by Smith. The Dirichlet and Neumann conditions are summed incrementally at the boundaries of the finite element or finite difference region of the infinite medium to eliminate the reflections. This incremental approach has the great advantage of eliminating reflections as soon as they occur. Consequently, multiple reflections are avoided, and the problem of several solutions, as required by the original Smith formulation, does not arise. The numerical solution is performed once only except around the boundary where two solutions are necessary.

● **6.12-81** Tow, D., **CRUNCH-2D: a two-dimensional computer program for seismic analysis of the HTGR core,** *GA-A14765,* General Atomic Co., San Diego, California, Feb. 1978, 163.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

An analytical procedure has been developed for determining the dynamic response of the HTGR (high temperature gas-cooled reactor) core under seismic excitation. This procedure, called CRUNCH-2D, has been programmed for numerical solution on the UNIVAC-1110 digital computer. CRUNCH-2D is a general two-dimensional computer code capable of analyzing the full array of a horizontal planar layer of HTGR core including the permanent side reflector blocks and the spring pack system. Each block of the CRUNCH-2D model represents one column of the reactor core and is connected to the core support floor by means of column springs and viscous dampers. The core support floor is represented by a single block. Seismic excitation is described by the PCRV motion. The code is capable of analyzing excitation input applied simultaneously in two mutually perpendicular horizontal directions. The CRUNCH-2D collision model may be represented either as a standard spring-damper model or as an impulse-momentum model in parallel with a spring-damper. Included in the report are the theoretical formulation of the analytical problem, a user's manual to describe the input and output format, and sample problems.

● 6.12-82 Marini, A. A., Augenti, N. and Santosuosso, A., **Introduction to the dynamics of discrete systems,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 71, 13.

In the dynamic analysis of structures, problems are mostly approached by using a number of simplifying assumptions to reduce an analytical model to one with a finite number of degrees-of-freedom. In this paper, the development of the equations of motions of such discrete models is investigated and a generally valid formulation and a systematic approach to solving the problem are suggested. The underlying assumptions making it possible to arrive at linear equations and to ensure that the superposition principle will apply involve the consideration of a field of displacements that are small with respect to the structural dimensions and the supposition that the deforming elements can be characterized by a linear elastic law. Damping actions are assumed to be proportional to velocities, while external stresses can be taken into account by using several load conditions, each characterized by synchronous forces, so that the dynamic investigation may be carried out for each such condition separately, and so that the overall effect at any given time may be obtained by superposition of the corresponding individual effects evaluated at the same time.

● 6.12-83 Taoka, G. T., **System identification of tall vibrating structures,** Dept. of Civil Engineering, Univ. of Hawaii, Honolulu, July 1979, 116.

This report investigates the best procedure, or the best systems identification method, for analyzing ambient vibration data to identify structural response parameters and attempts to determine by how much those parametric estimates evaluated under very low levels of excitation differ from the values to be expected when a structure is subjected to much higher levels of excitation, such as those caused by vibration shaking devices, or under severe wind or earthquake conditions.

● 6.12-84 Thompson, R. W., **MCOCO: a computer program for seismic analysis of the HTGR core—volume 1: user's and theoretical manual,** *CA-A14764, V. 1,* General Atomic Co., San Diego, California, Apr. 1978, 106.

This report presents documentation of the MCOCO (Multiple COre COlumn) computer program. The program was generated to perform dynamic analysis on a gas-cooled reactor core, which, structurally, is not only nonlinear but also discontinuous. The report may be used as both a theoretical and user's manual for the MCOCO code. Input for the program consists of geometric and dynamic data (mass, spring constants, etc.), and output includes dowel forces, element collision forces, spring pack forces, and core support floor forces. Core and boundary motion are also provided as output and, as an option, may be utilized to generate SC-4020 or CALCOMP plots. The code was originated by T. H. Lee and the current version was developed by the author.

● 6.12-85 Guilinger, W. H., Shah, V. N. and Bohm, G. J., **Seismic response of a structure subjected to rotational base excitation,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 8/7, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A modal superposition method which can be used to perform the seismic analysis of a structure subjected to translational and rotational base excitation is presented. Discussed are two different approaches to derive the equations of motion of the structure. In the first approach, the reference axes are fixed in space and the equations of motion are derived with respect to these axes. In the second approach, the reference axes are rigidly fixed at the base of the structure. This approach is generally used when the structure is subjected to translational base excitation alone. For rotational base excitation, the equations of motion are shown to become nonlinear as a result of the presence of the Coriolis acceleration term.

The first approach is used to derive the equations of motion. These equations may be integrated by the direct integration method or by the modal superposition method. For a long time history analysis, the computer cost of using the direct integration method is significantly greater than that of using the modal superposition method. The latter

● *See **Preface,** page v, for availability of publications marked with dot.*

method is given in this paper. The equations of motion have time-dependent displacement boundary conditions. The dependent variables are transformed so that the boundary conditions become homogeneous. The modal superposition method is applied to the transformed equations of motion, and conclusions about the use of this procedure are discussed.

The modal superposition method is applied to the seismic analysis of a building subjected to translational and rotational excitation. The displacement results and the computer cost of this analysis are compared with those of using the direct integration method. The computer cost associated with the modal superposition method is significantly lower than that associated with the direct integration method.

● **6.12-86** Ohsaki, Y. et al., **Phase characteristics of earthquake accelerogram and its application,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

As the input earthquake motion for the seismic design of nuclear power plant structures and equipment, an artificial time history compatible with a smoothed design response spectrum is frequently used. This paper deals with a wave generation technique based on phase characteristics in earthquake accelerograms as an alternative to the envelope time function. The concept of phase difference distribution is defined to represent the phase characteristics of earthquake motion. The procedure proposed consists of the following steps: (1) specifying a design response spectrum and deriving a corresponding initial modal amplitude; (2) determining a phase difference distribution corresponding to an envelope function, the shape of which is dependent on the magnitude and epicentral distance of an earthquake; (3) deriving the phase angles at all modal frequencies from the phase difference distribution; (4) generating a time history by means of an inverse Fourier transform on the basis of the amplitudes and the phase angles thus determined; (5) calculating the response spectrum; (6) comparing the specified and calculated response spectra, and correcting the amplitude at each frequency so that the calculated response spectrum will be consistent with the specified spectrum; (7) repeating steps 4 through 6, until the specified and calculated response spectra match with sufficiently accurate consistency. The procedure described in this paper is compared with other procedures.

● **6.12-87** Powell, G. H., **"Missing mass" correction in modal analysis of piping systems,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 10/3, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In mode-by-mode dynamic analyses of seismic response, an approximate solution is obtained because only a limited number of modes is considered (in U.S. practice, typically all modes up to 33 Hz). Errors are usually small for such response parameters as pipe displacements and stresses because they are affected relatively little by the high modes. However, the error may be substantial for support loads because the influence of high modes on their values can be important. Substantial stress errors can also be present in stiff systems with few low-frequency modes. In effect, the truncation of the mode series means that some mass of the system is ignored. The distribution of this "missing mass" is such that the inertia forces associated with it will usually produce only small displacements and stresses. However, these forces will often produce significant support loads, and in stiff systems can produce significant stresses. An approach which is sometimes used is to assume that the missing mass consists of the masses at the support points. Support load corrections can then be made. However, this approach is oversimplified and potentially inaccurate. A more accurate correction can be made by determining the modal contributions to the mass of the system and obtaining the missing mass as the difference between these contributions and the actual mass. A rational and accurate correction for missing-mass effects can thus be made. This approach has the advantage that missing masses will exist not only at the supports but throughout the system. Hence, not only support load errors but also stress errors can be corrected. Further, the procedure applies to systems with out-of-phase anchor motions as well as systems in which all anchors move in phase, and to both response spectrum and time-history analyses. The theory of the correction is presented, the method of computer implementation is indicated, and an example is discussed.

● **6.12-88** Leimbach, K.-R. and Sterkel, H. P., **Comparison of multiple support excitation solution techniques for piping systems,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 10/2, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Design and analysis of nuclear power plant piping systems exposed to a variety of dynamic loads often requires multiple support excitation analysis by modal or direct time integration methods. Both methods have recently been implemented in the computer program KWUROHR for static and dynamic analysis of piping systems, following a previous implementation of the multiple support excitation response spectrum method. The extension of the time history analysis to cover multiple support excitations was prompted by discussions with licensing authorities about the validity of the mean value computations such as root mean square, sum of the absolutes and superposition formulas in the U.S. Regulatory Guide for displacements, and stresses and absolute accelerations, involving results from a multiple support response

● *See **Preface,** page v, for availability of publications marked with dot.*

spectrum analysis. Results using these methods can only be examined by carrying out an equivalent time history analysis which does not distort the time phase relationship between the excitations at different support points. Another point of discussion is multiple versus single support excitation. A single support excitation analysis is computationally straight forward and tends to be on the conservative side as shown by numerical results. On the other hand, a multiple support excitation analysis does not incur much more additional computer cost than the expenditure for an initial static solution involving three times the number, L, of excitation levels, that is, 3 L static load cases. The multiple support analysis gives, however, much more realistic results than a single support excitation analysis can accomplish.

A number of typical nuclear plant piping systems have been analyzed using single and multiple support excitation algorithms for (1) the response spectrum method, (2) the modal time history method with use of the Wilson, Newmark, and Goldberg integration operators, and (3) the direct time history method with use of the Wilson integration operator. Characteristic results are presented to compare the computational quality of all three methods.

● **6.12-89** Sackman, J. L. and Kelly, J. M., **Equipment response spectra for nuclear power plant systems,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 9/1, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

An analytical method is developed whereby a simple estimate can be obtained of the maximum dynamic response of light equipment attached to a structure subjected to ground motion. The natural frequency of the equipment, modeled as a single degree-of-freedom system, is considered to be close or equal to one of the natural frequencies of the N-degree-of-freedom structure. This estimate provides a convenient, rational basis for the structural design of the equipment and its installation. The approach is based on the transient analysis of lightly damped tuned or slightly nontuned equipment-structure systems in which the mass of the equipment is much smaller than that of the structure. It is assumed that the information available to the designer is a design spectrum for the ground motion, fixed-base modal properties of the structure, and fixed-base properties of the equipment. The results obtained are simple estimates of the maximum acceleration and displacement of the equipment. The method can also be used to treat closely spaced modes in structural systems, where the square root of the sum of the squares procedure is known to be invalid. This analytical method is also applied to nontuned equipment-structure systems for which the conventional floor spectrum method is mathematically valid. A closed-form solution is obtained which permits an estimate of the maximum equipment response to be obtained without the necessity of computing time histories as is required by the floor spectrum method.

● **6.12-90** Drenick, R. F. et al., **Critical seismic response of nuclear reactors,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 8/4, 7. (For a full bibliographic citation, see Abstract No. 1.2–20.)

A new method is described for the assessment of structural earthquake resistance, and results are reported that are obtained by the application of the method to three nuclear reactor installations. The method leads to assessments which are believed to be inherently more reliable than those derived by others currently in use or under consideration. This high level of confidence is admittedly obtained as a result of a certain degree of conservatism inherent in the method; however, such a degree of conservatism may well be justified for structures as important as nuclear reactors.

● **6.12-91** Ahmed, H. U. and Ma, D., **A study of structural attachments of a pool type LMFBR vessel through seismic analysis of a simplified three dimensional finite element model,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/5, 10. (For a full bibliographic citation, see Abstract No. 1.2–20.)

A simplified three-dimensional finite element model of a pool-type LMFBR for use in conjunction with the computer program ANSYS is developed and results of a seismic analysis are presented. Various structural attachments for a pool-type LMFBR such as a reactor vessel skirt support, a pump support, and reactor shell–support structure interfaces are studied. This study also provides some useful results on the use of the equivalent viscous damping approach, and some improvements in the equivalent viscous damping method are recommended. This study also sets forth guidelines for detailed three-dimensional finite element seismic analysis of pool-type LMFBR.

● **6.12-92** Aziz, T. S. and Duff, C. G., **Seismic interaction effects for steam generators in CANDU 600 MWe nuclear power plants,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/7, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

Typical CANDU-PHW 600 MWe nuclear power plants contain four identical steam generators (SG). Because of space limitations around the fueling machine area, each one of these SG's is supported by a single column approximately 45 ft long which is anchored to the base slab at the bottom. The SG itself is housed in an internal box concrete structure. Seismic restraints and/or snubbers are used to support the SG laterally from this internal box structure. Conventionally, these SC's are designed by the use of an envelope floor response spectrum for the internal structure as an upper bound on the seismic response of light secondary systems. Nevertheless, mass coupling effects between the SG and the internal structure may be important since the SG has a considerable mass and is supported along most of the full height of the internal structure. An obvious solution to account for the coupling effects is to utilize an elaborate dynamic model which incorporates the different SG's, the reactor, and the reactor building into one dynamic model. Recent theoretical work by the authors in this area drew attention to some of the fallacies of using elaborate coupled models which involve small modal mass ratios for the secondary systems. Thus, a practical solution to account for the beneficial seismic interaction effects for secondary systems like SG's is lacking. The paper presents a substructuring technique to overcome the difficulties associated with using a coupled model with small modal mass ratios. The technique accounts for interaction effects as well as for multiple input motions and provides a clear understanding of the beneficial coupling effects. Typical results using this substructuring technique combined with a spectrum analysis for a typical CANDU nuclear power plant on a soil site are presented and discussed. Guidance on the validity of using the approach for other similar secondary systems applications is given.

● **6.12-93** Lin, C.-W., **Seismic response analysis of nuclear power plant auxiliary mechanical equipment,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol K(b), Paper K 11/6, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

In this paper, the prevailing modeling techniques for analyzing auxiliary mechanical equipment for nuclear power plants is reviewed in accordance with current technological development. For example, in the modeling of valves, it has been recognized that the majority of valves are rigidly designed (i.e., having natural frequencies greater than 33 Hz). Substantial simplification has been made by vendors to reduce the models. A one-mass representation of the rigid valves is not an uncommon assumption. However, some recent test results have shown that there are valves with flexible parts which can only be qualified using proper assumptions and models with sufficient details. In this paper, some results obtained in these test and analysis programs will be discussed to provide insight to the proper modeling of these components. Also, a considerable amount of equipment data have been accumulated for plants under construction or in operation. A compilation of these data into usable forms, such as by statistical means, would be a very useful tool for the safe and economical design and analysis of nuclear power plant equipment. Some of the data obtained toward this goal are illustrated.

● **6.12-94** Cambien, R. B. and Hennart, J. C., **Arguments in favour of structures, systems and equipment seismic qualification by analysis,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/2, 9. (For a full bibliographic citation, see Abstract No. 1.2–20.)

This paper discusses the application of analytical methods for the seismic qualification of nuclear power plants and provides criteria for appraisal of a seismic analysis, including the importance of consistency between experimental and analytical results.

● **6.12-95** Morrone, A. and Sigal, G. B., **Combination of torsional, rotational and translational responses in the seismic analysis of a nuclear power plant,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 8/8, 8. (For a full bibliographic citation, see Abstract No. 1.2–20.)

A seismic analysis performed on a "nuclear island building" (NIB) complex of a nuclear power plant and the methods developed to combine torsional, rotational, and translational responses are described. The NIB complex analyzed consists of various buildings supported on a common foundation mat and tied together from the underground foundation to the roof levels. Three independent building mathematical models were used for the three components of the earthquake with a lumped-mass method utilizing direct integration of the coupled equations of motion. The input ground acceleration time histories were based on three 20 sec long statistically independent records for which the normalized response spectra enveloped those of Regulatory Guide 1.60. A linear stochastic model was used to generate these records which simulated strong-motion earthquakes. Because of varying site characteristics, soil material properties were calculated considering different ranges of soil moduli below and above the foundation.

For the response spectrum analysis of equipment supported on the building floors, seven response spectra (three translational, two torsional, and two rotational) were developed at each node for each of the two earthquakes (OBE and SSE). These seven spectra were required to completely define the floor motion since each building node was given three degrees-of-freedom in the horizontal models (E-W and N-S) and one degree-of-freedom in the vertical model. The general formulation is given initially whereby these seven response spectra are applied individually for the equipment analysis. However, since this general procedure is time-consuming, a more practical, simplified procedure which combines the seven spectra and reduces them to the conventional three response spectra (two horizontal and one vertical) has been developed. This procedure combines the translational spectra with the translational components produced by the torsional and rotational spectra at a particular location of the equipment away from the node point. The combination is made on the square root of the sum of the squares basis. Therefore, this simplified procedure requires that the resulting directional effects (stresses, deflections) be combined absolutely. The

● *See **Preface,** page v, for availability of publications marked with dot.*

application of the simplified procedure is demonstrated to yield results equal to or greater than those with the general procedure. For uncoupled equipment, the simplified procedure gives the same results as the general procedure. For coupled equipment, the simplified procedure is always conservative with the amount depending on the degree of directional coupling of the particular equipment.

● **6.12-96** Atalik, T. S., **On upperbound instructure response spectra,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 9/3, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Generally, in-structure response spectra are constructed using the time history analysis technique whereby a synthetic accelerogram is first applied to the base of a structure, and the resulting responses are filtered through simple oscillators to record their maxima. However, it is possible to show that for a given simple oscillator damping and natural frequency the corresponding spectral acceleration of the response of the ith degree-of-freedom when the structural system is subjected to a prescribed ground motion is equal to the maximum absolute acceleration of that degree-of-freedom when the system is excited by a support motion which is obtained by filtering the prescribed ground motion through the simple oscillator. This is achieved by reversing the order of the integration in the mathematical expression for a spectral value. The procedure enables one to construct in-structure spectra by the response spectrum method using as input the spectra of the filtered motions called the secondary spectra. This paper defines upper-bound secondary spectra and thus upper-bound in-structure spectra and applies the spectra to cases where such responses are of interest. It is shown that the procedure may be refined to any desired degree of accuracy.

● **6.12-97** Agrawal, K. M., Katramadakis, T. and Thom, A. L., **Computer applications in an international consulting environment,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, I-15-23.

The consulting industry is largely responsible for translating research into application. Solution procedures and accuracy requirements depend upon application and input parameters. For medium- to large-sized consulting companies, independence from large commercial programs provides for flexibility by permitting the economical and quick modification of solution procedures to suit special problems. The modular approach to computer programming is recommended in which standardized subroutines can be simply added or deleted.

● **6.12-98** Geradin, M. and Hoggs, M., **Efficient strategies in nonlinear implicit structural dynamics,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-61-66.

The iterative methods for solving nonlinear equations of dynamic equilibrium which arise in implicit time integration are discussed. A quasi-Newton algorithm is proposed as an alternative to the classical Newton-Raphson method, and the possibility of updating the successive iteration matrices is examined. The effectiveness of the method is discussed for two applications.

● **6.12-99** Eshpuniyani, B. L., **Finite difference analog for thick plates subjected to impulsive loading,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, III-73-76.

A three-dimensional finite-difference analog is proposed for the solution of plate problems. The effects of rotatory inertia and shear deformation are taken into account. The stability and convergence of the analog are established. The required solution steps are listed and an example is given. Time-displacement curves are drawn for a moderately thick plate subjected to impulsive loadings. The results are compared with a corresponding Navier-type solution of the system.

● **6.12-100** Ahamad, V. and Ganesan, T. P., **Analysis of core wall structures by finite element method,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-63-67.

A computer program is described for analyzing core walls using the finite element method. The finite element used for the walls and slabs is a combination of a plane stress element and a plate bending element. The program can also be used for analyzing any type of shear wall building having an orthogonal system of walls, frames, and floor slabs. A general flow chart of the program is given. Two subroutines are available for use as equation solvers. This makes the program equally efficient for analyzing small as well as large structures. The system size and bandwidth of the stiffness matrix are practically unlimited. The basic steps in the solution are explained.

● **6.12-101** Paramasivam, P. and Sham, K. M., **Simplified computer analysis of shear wall-frame building,** *International Conference on Computer Applications in Civil Engineering, October 23-25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-37-42.

This paper presents an iterative method which is suitable for small-scale computer applications in the analysis of multistory shear wall-frame buildings subjected to both lateral and vertical loading. The method provides

● *See **Preface**, page v, for availability of publications marked with dot.*

detailed stress results and lateral story deflections. The shear wall elements in the building are transformed into equivalent frames and a frame analysis based on an iterative method is used to analyze the idealized structure. Numerical results are presented, and the results are compared with those obtained by means of other methods. The proposed method is especially suitable for general design offices equipped with minicomputers because of its simplicity in formulation and lesser requirements of computer storage.

● **6.12-102** Rao, T.V.S.R. A., Loganathan, K. and Gallagher, R. H., **A discrete stiffener element for doubly-curved shells,** *International Conference on Computer Applications in Civil Engineering, October 23–25, 1979, Proceedings,* NEM Chand & Bros., Roorkee, India, 1979, IV-127–133.

The paper contains a critical review of various developments of discrete stiffener elements for the analysis of eccentrically stiffened plates and shells. A formulation for a discrete stiffener element compatible with the doubly-curved triangular arbitrary deep shell element developed by Thomas et al. is presented. A few examples demonstrate the effectiveness of the formulation.

● **6.12-103** Kurosaki, A. and Kozeki, M., **Fatigue analysis method for seismic structural response,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 8/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Cyclic characteristics of seismic structural response are of importance in fatigue analysis. The current procedure to evaluate fatigue damage is generally based on the maximum stress value and the conservatively estimated number of occurrences. This procedure, however, is likely to lead to unduly overestimated results.

In this paper, a practical procedure is proposed for estimating the appropriate cumulative damage caused by seismic structural response. To take the random characteristics of seismic response into account, the basis for the theoretical development of the paper is given by a statistical approach. However, the paper also deals with the method for estimating cumulative damage in terms of a proposed diagram and some simple equations, which can be applied conveniently to the conventional design procedure without consideration of the complicated statistics.

A stationary random process with Gaussian distribution is assumed for the theoretical approach in the time domain. Then, based on Miner's cumulative damage concept, the equation estimating the expected cumulative damage E(D) can be formulated in terms of the probability density function p(y) of stress extreme y, the expected total number of extremes E(M), and some constants given by a fatigue curve. The equation is theoretically described by an infinite integration associated with p(y) which is a function of variance Q and index of randomness ϵ. Since alternating stresses lower than the stress at 10^6 cycles on a fatigue curve can be neglected in general and stress extremes higher than the stress at about 10 cycles on the fatigue curve are proven to be meaningless from an engineering standpoint, these two stresses on the fatigue curve can be taken respectively as a lower and an upper boundary to the integration. As the result, a diagram of the relation between Q and E(D)/E(M) can be obtained by taking ϵ as a parameter. This means that if Q, E(M) and ϵ are evaluated, E(D) can be easily given by this diagram. It is also shown in the paper that Q, E(D) and ϵ can be obtained by the variance of an input excitation and the modal response characteristics. When a stress time history is given, on the other hand, the cumulative damage can be computed almost exactly by means of some conventional methods. The results of E(D) derived from the proposed method are compared with those which are obtained by the conventional methods and close agreement is shown. Based on this investigation, it is concluded that the newly proposed method yields an adequate estimate of the cumulative fatigue damage caused by seismic structural response.

● **6.12-104** Mondkar, D. P. and Powell, G. H., **Further developments of capabilities in the program ANSR for nonlinear finite element analysis,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 1/4, 6. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A progress report on the development of a general purpose program ANSR for the static, dynamic, and earthquake response analysis of nonlinear finite element systems was presented at the SMiRT-4 conference. Since that time, research and development of new capabilities for the ANSR program have continued. The main thrust of these developments has been in areas of (a) new nonlinear finite elements in the ANSR element library; (b) a comprehensive analysis restart option; (c) prescribed static displacement and multi-support excitation dynamic analyses capability; (d) solution of in-core and out-of-core, unsymmetric system equations. The objective of this paper is to briefly summarize these developments.

● **6.12-105** Crutzen, Y., **A thin shell dynamic transient non-linear analysis program,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 5/9, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Using computerized analysis, the finite element computer program SLOOFDYN has been developed for fast (wave-propagation-type) transient dynamic nonlinear response of thin shell structures. Iron's isoparametic shell element SEMILOOF has been implemented. For the analysis of large displacement dynamic problems, the present approach utilizes the convective coordinate formulation, as introduced by Belytschko, which is favorably combined with an explicit time integration procedure. Problems with large displacements and finite rotations but small strains can be treated with the use of an efficient technique capable of calculating rigid displacements and deformation displacements within the element.

The material inelastic behavior is described by means of elastoplastic relations using Von Mises' yield criterion and an isotropic strain-hardening flow rule according to a postulate of Drucker's. A particular improvement of the computer code is the possibility to follow accurately the progressive plastification across the shell thickness. The material viscosity has been introduced by means of a damping proportional to the material density. A lumped-mass explicit technique permits the direct computation of the nodal accelerations, velocities, and displacements from the basic equations of motion. The fact that the assembly of large mass and stiffness matrices and their resolutions are avoided results in significant reductions in computer time.

Because dynamic transient analyses are expensive with regard to computer costs in three-dimensional situations, and because the time step of an explicit algorithm is always bounded for stability in computation, severe limitations exist with the use of brick isoparametric elements or very simple finite elements. Therefore, the implementation of the SEMILOOF element represents an improvement in structural dynamic analysis.

● **6.12-106** Malkus, D. S., **Penalty methods in finite element analysis of fluids and structures,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 6/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper discusses the use of penalty techniques in Galerkin finite element equations. It shows that earlier results relating penalty methods to mixed and Lagrangian multiplier methods through the use of reduced/selective numerical integration formulas extend to problems in which there is no extremum principle. It is also shown that penalty techniques can be employed in nonlinear dynamic problems and can lead to substantial computational savings at each time step. The penalty techniques described can lead to computational benefits arising from the ability to impose constraints without Lagrangian multiplier unknowns, but the techniques also may lead to the costs associated with the slowing of convergence rates of certain nonlinear iteration schemes, the ill-conditioning of certain iteration matrices, and the complication of some mesh refinement schemes. Nevertheless, in many problems, the benefits well outweigh the costs.

● **6.12-107** Hallquist, J. O., **Implicit treatment of the large deformation response of inelastic solids with slide-lines,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 6/8, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

An implicit, large deformation, large strain finite element computer program, called NIKE2D, has been developed for analyzing the static and dynamic response of two-dimensional axisymmetric and plane strain solids. Slide-lines, based on a penalty function formulation, permit arbitrary zoning along material interfaces. Such interfaces may be tied and free to slide but not separate, or may be free to slide and separate. A variety of elastic and inelastic material models are implemented. Nearly imcompressible behavior that arises in plasticity problems and elasticity problems with Poisson's ratio approaching 0.5 is taken into account in the element formulation. A typical application is presented.

● **6.12-108** Zeitner, W., **A numerical method for complex structural dynamics in nuclear plant facilities** (Ein numerisches Verfahren zur Berechnung komplizierter dynamischer Probleme bei Kernkraftwerkskomponenten, in German), *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 6/7, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Because of the constraint conditions of a system, the solution of dynamic problems is often connected with difficulties in establishing a system of equations of motion. Such constraint conditions may be of a geometric nature as for example gaps or slidelines or they may be compatibility conditions or thermodynamic criteria for the energy balance of a system. The numerical method proposed in this paper for the treatment of a dynamic problem with constraint conditions requires only the establishing of equations of motion without considering constraints. This leads to a relatively simple formulation. The constraint conditions are included in the integration procedure by means of a numerical application of the Gaussian principle.

● **6.12-109** Orkisz, J. and Wrana, B., **A method of solution of the eigenproblems of large structural systems in an arbitrarily specified range,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 7/4, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Presented is a method for calculating all eigenvalues and eigenvectors of an eigenproblem in an arbitrarily specified range of an eigenspectrum for two real high-rank symmetric matrices. A version of the method of subspace iterations is used. The version includes two new concepts:

● See *Preface, page v, for availability of publications marked with dot.*

(1) an extension of the symmetric version of the simultaneous vector iteration method to an arbitrary domain of the eigenspectrum and (2) application of the Chebyshev acceleration in a nonclassical way, that is, by use of the direct form of the product of subsequent linear terms instead of the recurrence formula commonly used. A computer program written in FORTRAN IV is developed, and structural vibration problems are solved.

● **6.12-110** Krings, W., **Modal analysis and estimation of the calculation errors** (Modale Analyse und Bestimmung der Rechenfelder, in German), *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. M, Paper M 7/6, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The integration of a system's equations by means of modal analysis must be carried out for the lower modes, which excite the system in a dynamic manner. An upper value for these eigenfrequencies can be given by the load function. To integrate the modal differential equations, the exact solution is used as a transfer method. This time-saving formulation is unconditionally stable. The error influence of the nonconsidered modes for the displacements, accelerations, and stresses is predicted by means of a simple static solution, because for the higher modes, the system response is quasistatic. Thus, it is not necessary to know the higher modes.

● **6.12-111** Benjamin, J. R., **The development of time-history design criteria for uncertain transient loads**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. M, Paper M 8/3, 6. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents a procedure for the time-history decomposition of the records of highly transient phenomena and the development of criteria from the decompositions. The technique is to decompose the record into a set of wave trains. Each such train is composed of segments, all with the same period, but each segment amplitude is independent of all others and the segments can be in or out of phase with adjacent segments. Each wave train consists of a series of transients. The sum of the wave trains is equal to the original record. The decomposition of such records gives direct data upon which time-history criteria can be developed.

● **6.12-112** Meyer, C., **Quasi-nonlinear dynamic analysis**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. M, Paper M 10/4, 6. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes a solution strategy that may be implemented effectively in linear structural analysis programs in order to expand their capabilities to cover quasi-nonlinear problems as well, while preserving the efficiency of the existing solution algorithms. If the nonlinear effects are treated as corrections to the incremental load vectors, the number of operations is proportional to the number of iterations and the number of time steps during which the stiffness is different from the original stiffness. If the structural stiffness is redecomposed each time the stiffness changes, the apparent increase in effort can be reduced appreciably if the unknowns are numbered so that the degrees-of-freedom with nonlinear stiffnesses are numbered last, leaving the reduced stiffness of the modified system largely unaffected by the change. In most cases, such a redecomposition will be more economical than using iteration. Moreover, the numerical effort required in addition to a linear analysis is rather small for many practical applications. A one-dimensional bar or spring element with a trilinear force-displacement curve is adequate to model a large number of the quasi-linear phenomena mentioned above.

● **6.12-113** Tanimoto, B., Ishikawa, K. and Natsume, S., **Forced vibration of beams by eigenmatrix method**, *Journal of the Structural Division, ASCE*, **105**, *ST12*, Proc. Paper 15090, Dec. 1979, 2725-2749.

The eigenmatrix and the operational displacement methods are presented for the forced vibration problem of beams and frames. The differential equation for flexure can be derived from the classical Bernoulli-Euler theory, and the equation can be extended to take into account Timoshenko's theory. The stress-strain relationship can also be extended from Hooke's law to the viscoelastic Voigt law. Avoiding the prevailing lumped mass or finite element philosophy, the authors treat the structures as a continuum solid body as they appear. The method consists of the three traditional branches in structural analysis: (1) the eigenvalue problem, (2) the boundary-value problem, and (3) the initial-value problem. The eigenmatrix method is in a sense the "algebraic transfer matrix method," in which case the load term can be separated, and it is suited for one-dimensional structures. The operational displacement method is fitted for frames, in which case the complete stiffness matrix is tridiagonal.

● **6.12-114** Cecconi, S., Giuliano, V. and Lazzeri, L., **On the seismic design spectra for heavy components and comparisons with the usual FRS techniques**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 9/2, 6. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In this paper, the seismic response is evaluated for a heavy polar crane with natural periods the same order of magnitude as the periods of the supporting containment

● *See **Preface**, page v, for availability of publications marked with dot.*

structure. For this analysis, the floor response spectra technique typically used was considered inadequate because of the large resonance amplification in the equipment response which might produce many difficulties in the design of the equipment. An analysis has been conducted for a simplified, coupled equipment-supporting structural model subjected to the direct action of a ground response spectrum. For the supporting structure, a stick model has been used with soil-structure interaction simulated by the usual type of springs, while for the equipment, an equivalent lumped mass and spring model has been chosen. A parametric analysis has been carried out for the equipment for various fundamental periods and damping values. The purpose was to determine an acceleration-period function to be used in a subsequent appraisal of the maximum seismic response of the equipment.

Computed results are presented and compared with the floor response spectra. A substantial reduction that corresponds to the resonant periods of the supporting structure is obtained, while a good agreement exists for low and high periods, i.e., when the equipment is stiffly connected to the supporting structure (complete coupling) and when the equipment is very flexible (complete decoupling). The response spectra at the point of connection between the equipment and the supporting structure are presented. It is interesting to note that such spectra are not constant but that they, for the most part, decrease near the resonant periods of the supporting structure. It is concluded that, when dealing with the appraisal of the seismic response of heavy equipment, it is always convenient to analyze a coupled structure-equipment system as required by the usual regulatory guidelines. The use of the simplified floor response spectra techniques greatly overestimates the response of the equipment, at least close to resonance. However, because of the advantages in terms of actual accelerations and consequent structural design, the first, more sophisticated procedure should be used for the analysis of most heavy equipment including equipment not of primary importance, such as polar cranes.

● **6.12-115** Cecconi, S. et al., **On the effects of using wide range earthquakes,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/9, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In the seismic analysis of nuclear power plants, it is common practice to use spectra over a wide frequency range to represent envelopes of many earthquakes recorded on different soil conditions. However, this enveloping action should be conducted for the response of structures rather than for the input; and, particularly for nonlinear response resulting from plasticization or other nonlinear actions, one should question whether the enveloping action at two different stages yields similar results. To provide some answers to these questions, a limited number of calculations were performed. The research was conducted in the following stages: (1) Three synthetic time histories (A, B, C) have been generated by means of SIMQKE and another computer code. The time history envelope E is the spectrum given by regulatory guide 1.60. Each of the three time histories represents a high-, a medium-, or a low-frequency time history. (2) Typical stick models or frame models have been generated with a certain degree of multimodal response; the eigenfrequencies of the models have been changed so that the whole earthquake range is considered. (3) Elastic analyses have been performed by means of time histories and response spectra with earthquakes A, B, C, and E considered. Output data are given in terms of displacements and maximum acceleration; the SAP IV code has been used to perform the analyses. (4) Nonlinear analyses have been performed by means of the SAKE code; the development of plastic hinges at different moment levels has been postulated. The ratio of the yield moment to the maximum elastic moment recorded during the elastic analysis has been analyzed as a parameter and various values have been considered. Responses in terms of ductility ratios have been recorded for each run.

Some conclusions valid for the range of data considered may be drawn. In the elastic range, there is not much difference between the responses of the structures to earthquake E and the envelope of the responses to the three earthquakes A, B, and C. In the plastic range, there is an increase in the ductility response D with a decrease of the ratio R of the yield moment to the maximum elastic response; in any event, the relationship between the ductility and the ratio R is somewhat irregular. Typical D-R curves are given for various structural eigenfrequencies. In the plastic range, the response of the envelope earthquake is quite similar to the envelope of the responses to three different earthquakes.

● **6.12-116** Glockner, H.-J., Kemter, F. and Schmidt, G., **Evaluation of seismic movements of a pebble bed reactor core as basis for shaking experiments** (Berechnung seismischer Bewegungen des Cores eines Kugelhaufenreaktors als Grundlage fur Ruttelexperimente am Modell einer Kugelschuttung, in German), *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 12/7, 10. (For a full bibliographic citation, see Abstract No. 1.2-20.)

● **6.12-117** Aihara, S. et al., **The computer program system for structural design of nuclear power plant** (Das System zur bautechnisch-elektronischen Berechnung von Kernkraftwerk, in German), *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 1/5, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

This report introduces a system of computer programs for the design of a nuclear reactor building. The system consists of the following steps: (1) Modeling of the structure, including simplified data generation and plotting of the model. (2) Structural analysis, including many types of programs. There are about 20 to 50 load conditions, among which are seismic loads for two vertical and two horizontal directions, temperature loads for normal operating conditions and for accidental conditions, etc. In addition, there are 30 to 150 load combinations. Values for combined stresses caused by various loads are calculated by this program. Stresses for basic and combined loads are plotted. (3) Design of member sections, and plotting of structural calculations. (4) Plotting of stress, strain, and other diagrams, which are necessary for the design of a power plant and also of use in applying to governmental authorities for design approval. The major parts of a reactor building which can be analyzed by means of this system are (1) the foundation mat from rocking spring calculations and load data preparation to rebar evaluations; (2) the shielding shell from grid and element data preparation to rebar evaluations; and (3) the frames from load data preparation to rebar evaluations.

● **6.12-118** Hua, L.-C., **Super element model development and analysis on the Mark I torus structure,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 3/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The Mark I BWR pressure suppression system consists of a toroidal shell suppression chamber and a vent pipe system. The suppression system is presently under structural performance evaluations for the static and dynamic loads resulting from the loss-of-coolant accident (LOCA) and safety relief valve (SRV) discharge. This evaluation necessitates the accurate determination of the system response and structural stresses under all SRV- and LOCA-related loading conditions, including seismic loading.

This report describes the development of a finite element model and analysis procedures, using the "super element" capability of the NASTRAN computer program, for the static and dynamic analysis of the Mark I torus structure and presents the results of the analyses performed for a specific Mark I torus. One important consideration in the torus finite element model development was that the model be sufficiently refined so that it could be used for analyzing all necessary loading conditions, and could yield accurate enough stress information for a direct code evaluation. Thus, a very large finite element model is necessary. The model reported here consists of 5998 nodes and 6512 elements with 35,988 total system degrees-of-freedom to represent one-half of a torus structure. In comparison with a number of models developed to date for the torus structural evaluation, this model is the most comprehensive.

Two static and three dynamic analyses were performed based on this model. The first static analysis considered the combined loading of the LOCA pressurization load and the dead load including the hydrostatic pressure load. The second static analysis considered the peak pressure distribution of the peak chugging load for the purpose of determining the dynamic amplification factors of the structure caused by dynamic chugging loads. The dynamic analyses performed were for 8 and 20 Hz dynamic chugging loads. Two types of water mass distribution methods (radial distribution and hydrostatic distribution) were considered. This was done to study the primary modes associated with the different types of water mass distribution.

The results of the analyses follow. The stresses in the structure are highly sensitive to the excitation frequencies. In order to assure that every component of the structure is excited to its maximum level within the frequency range, a complete evaluation should consider many different excitation frequencies. There are significant coupling effects between torus segments. These effects can be properly studied only with the type of model presented in the paper. The frequency content and mode shapes are significantly affected by the water mass distribution methods. The radial mass distribution induces oval shapes modes of the torus while the hydrostatic mass distribution induces bounce modes of the whole structure.

● **6.12-119** Morel, A. et al., **Comparison between a 3D photoelastic model and an axisymmetric finite element calculus,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 3/8, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The results obtained with a three-dimensional photoelastic model of a reactor building of an LMFBR Super-Phenix with its underlying soil are compared with the results of a detailed finite element analysis obtained with an axisymmetric model. The comparison focuses on settlements and differential deformation of the raft foundation and on stress and shear in the exterior shell of the building and in the radial walls bonding the shell to the foundation mat. In general, the results are in agreement; but there are some differences with regard to certain areas, the origins of which are geometric differences between the models and different applications of loads and the limits of each method with regard to the size of the mesh for the finite element analysis and with regard to the physical perturbations for the photoelastic model.

● **6.12-120** Wu, S. T., Chiu, K. D. and Odar, E., **Approximations for dynamic modeling,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 10/5, 5. (For a full bibliographic citation, see Abstract No. 1.2-20.)

● See *Preface,* page v, for availability of publications marked with dot.

To perform a dynamic analysis, a complicated system is frequently replaced with an appropriate equivalent simplified member. The most common way of finding such an equivalent member is to place a lumped mass and a mass moment of inertia at the corresponding floor level of a beam so that the significant frequencies of the beam would match those of the original structural system. The effects caused by the linked members between the wall and column as well as by the unsymmetrical geometric effects can be taken into consideration by making a 3-D static analysis. Nevertheless, the rotational stiffness is in general difficult to determine. The simplest way to find such floor characteristics might be the least square method or the collocation method.

The collocation approach is proposed for use with the multipoint constraint technique. Linear relations to specify the nodal displacements can be easily accomplished. For a two-dimensional symmetrical structure, results found by use of the collocation method should be close to those obtained by use of the least square method. Numerical results were calculated for a three-span frame with a shear-wall at the center span for varying wall thicknesses and span lengths. The rotational stiffness values are very close for corresponding cases using different methods. For a three-dimensional problem, numerical comparisons are also provided for selected structural layouts by varying the locations and the dimensions of the shear walls and the columns. In general, a unique solution is difficult to obtain for the following reasons. (1) The complicated geometric layout makes it difficult to predict the dynamic behavior. (2) The floor characteristics cannot be described with one significant rotational mode and one translational mode. Although no general principles can be drawn from this study, certain guidelines are recommended for evaluating the effective stiffness of structural members. These guidelines will be helpful in making approximations to irregular floor conditions, such as floor openings, T-beam effective flanges, etc. Material nonlinearity may be a problem during heavy load conditions. It is very expensive to evaluate structural behavior during each time step. Discussions are also provided on the effective-strain method to be applied to the cracking of concrete.

● **6.12-121** Chiatti, G. and Sestieri, A., **Analysis of static and dynamic structural problems by a combined finite element-transfer matrix method,** *Journal of Sound and Vibration,* **67,** *1,* Nov. 8, 1979, 35–42.

The combined use of the finite element and transfer matrix techniques (FETM) for the study of dynamic problems was proposed a few years ago, in order to overcome the large amount of computer storage and long computation time that the finite element technique often requires. In this paper, some interesting applications are emphasized for both static and dynamic problems of structures. A great deal of attention has been paid to the use of shell isoparametric elements for very thin structures, where the usual numerical integration by a two-by-two Gaussian quadrature of the stiffness matrix leads to an ineffective increase of stiffness in the structure. Particularly appealing seems to be the use of quadratic shell elements in the FETM method, because, even with a reduction in the total number of elements of the structure, it is possible to increase the accuracy of results. Computation time is appreciably reduced by this method, because of the notable lowering of the final matrix order, the manipulation of which gives the solution of the problem. Some results for natural frequencies of a thin plate are presented, showing a favorable agreement with those obtained by other proposed methods.

● **6.12-122** Stephen, N. G. and Levinson, M., **A second order beam theory,** *Journal of Sound and Vibration,* **67,** *3,* Dec. 8, 1979, 293–305.

A second-order beam theory which takes into account shear curvature, transverse direct stresses, and rotatory inertia is presented. The governing differential equation is similar in form to the Timoshenko beam equation but contains two coefficients, one of which depends on cross-sectional warping just as does Cowper's expression while the second, although similar in form, also includes terms dependent on the transverse direct stresses. Comparison is made with exact and other approximate theories for particular cases.

● **6.12-123** Wang, P. C. and Yun, C. B., **Site-dependent critical design spectra,** *Earthquake Engineering & Structural Dynamics,* **7,** *6,* Nov.-Dec. 1979, 569–578.

A new type of seismic response spectrum is presented. It is based on the concept of a critical excitation, which is defined in this paper as an excitation among a certain class of excitations that will produce the largest response peak for a design variable of interest. Site conditions, namely rock, stiff soil and deep cohesionless soil, are taken into account by means of the definition of the class of allowable excitations. The response spectra thus produced are compared with others that have been proposed or used in the past. Results indicate that they lead to a realistic if somewhat conservative assessment of structural earthquake resistance. The response spectra are derived under assumptions that are rather well supported by seismological observation and avoid other questionable assumptions, especially those regarding the statistics of ground motions. These critical response spectra may thus inspire greater confidence on the part of their users than those currently proposed or relied upon.

● **6.12-124** Spanos, P.-T. D., **Numerical simulations of a Van der Pol oscillator,** *TICOM Report 79-9,* Texas Inst. for Computational Mechanics, Univ. of Texas, Austin, Aug. 1979, 24.

● *See **Preface,** page v, for availability of publications marked with dot.*

Numerical simulations of the statistics of the amplitude of the response of a lightly damped Van der Pol oscillator under a Gaussian white excitation are presented. Computational aspects of several parameters of the numerical model of the Gaussian white process are discussed. The numerical data obtained are used to assess the reliability of an approximate solution for the stationary probability density function of the response amplitude. The cost of computation of the numerical simulations is considered.

● **6.12-125** Kaiser, K., **Approximating a sequence of discrete points by means of elementary functions** (Automatische dialogunterstutzte Anpassung diskreter Punktfolgen mit stetigen Funktionen, in German) *Mitteilung 78-1,* Inst. fur Konstruktiven Ingenieurbau, Ruhr-Univ. Bochum, West Germany, Jan. 1978, 166.

Two methods are presented for approximating a sequence of discrete points by means of elementary functions. The first is a method of curve fitting that permits the recognition of and that analytically describes features characteristic of the original material in the form of an interactive graphic dialog. The second, developed from a Monte-Carlo method, is more generally applicable; by permitting the use of any type of elementary function, this method enables a nonlinear regression to be performed for all parameters. Unique functional connections result; there is no increasing tendency for approximation errors at the boundaries of intervals, which means that extrapolation or trend continuation beyond the boundaries of the intervals is possible.

● **6.12-126** Schrader, K.-H., **Primer for the F.E.M. concept MeSy and the programming system MESY-Mini** (*MeSy: Einfuhrung in das Konzept und Benutzeranleitung* fur das Programm MESY-MINI, in German), *Mitteilung 78-11,* Inst. fur Konstruktiven Ingenieurbau, Ruhr-Univ. Bochum, West Germany, Nov. 1978, 212.

This report is an introduction to MeSy, a finite element concept, and the programming system MESY-Mini. The program can be used to solve structural mechanics problems. Primarily, the program is useful as a tool for teaching and for solving small but possibly sophisticated problems without preparing external data. After a general introduction to the system, a user manual is provided, some hints for the programmer are given, and the main aspects of the theory are discussed. For a better understanding of the program organization and its theoretical background, an ALGOL source program is included.

● **6.12-127** Geradin, M. and Hogge, M. A., **Quasi-Newton iteration in non-linear structural dynamics,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 7/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In the context of nonlinear structural dynamics, implicit methods of solutions involving the tangent stiffness matrix K^t are often not competitive with explicit schemes because of the cost of the numerous updates of the iteration matrix which are generally required for a satisfactory rate of convergence. In an attempt to reduce this cost, the application of quasi-Newton methods seems to be particularly attractive; the underlying idea is to use an approximation to the inverse iteration matrix instead of the true inverse. The method is particularly well adapted to nonlinear dynamics where the displacement increments are necessarily kept small in order to achieve a sufficient accuracy in the time-marching procedure. A few rank-two corrections lead at each step to a proper evaluation of the iteration matrix; they involve only the calculation and combination of load vectors. The cost for updating the iteration matrix can thus be maintained at a much lower level than in the standard Newton procedure. The procedure can even be started with the direct stiffness matrix, thus making the availability of tangent stiffness calculations inessential. Special care is devoted to the critical steps of the formulation: efficient implementation of the rank-two correction in Gaussian elimination using the frontal concept; the minimum accuracy to be achieved in the line search process; the frequency at which a direct evaluation of K^t is desirable to maintain the convergence of the solution. The method is discussed using as an example a problem of structural dynamics in which strong geometric nonlinearities are exhibited. The results are compared with the results obtained by the standard Newton method.

● **6.12-128** Stanton, J. F. and McNiven, H. D., **The development of a mathematical model to predict the flexural response of reinforced concrete beams to cyclic loads, using system identification,** *UCB/EERC-79/02,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 206. (NTIS Accession No. PB 295 875)

This report describes the development of a mathematical model to predict the flexural response of reinforced concrete beams to cyclic loads. The objective is to take the first step towards the construction of a model which will predict accurately the nonlinear response of reinforced concrete framed structures when they are subjected to dynamic loads such as seismic disturbances. The model is constructed using system identification. The process consists of selecting a form for the model, and then using suitable mathematical techniques to adjust the numerical coefficients within it so that it reproduces as closely as possible the results of experiments.

The first essential is to understand the physical behavior to be reproduced. The response of reinforced concrete members to large cyclic loads is nonlinear and inelastic and it changes throughout the history of the load. Because it is so complicated, the physical behavior of the material and the mechanics which underlie it are investigated in considerable detail. A model form is then selected which divides the member into hypothetical layers. The material in each layer obeys an appropriate nonlinear constitutive law and the number forces are derived by integration across the cross section. The individual model which describes the steel behavior was developed especially for the purpose and is of particular interest. The experimental results to which the model was fitted were taken from a previous study in which a number of cantilever beams were subjected to cyclic lateral loads. Beams of several different geometries were tested, allowing the model to be appraised in a variety of configurations.

In addition to experimental results and an analytical model form, system identification requires a minimization procedure to find the optimum parameter values. Many algorithms exist for the purpose, and a number are investigated in order to select one with suitable characteristics. The identification was carried out in several stages. The first was to construct a model for the response of the steel reinforcement using data from axial tests on steel bars. Even this identification process contained several stages, because the original version of the model had constant parameters and it proved unable to reproduce the measured behavior adequately. The parameters were therefore made strain-dependent, and several cycles of modifying the model and re-identifying the parameters were necessary before a satisfactory match could be achieved. When the steel model was complete, it was incorporated into the global model. The steel parameters were held constant, and the concrete and bond-slip parameters were then identified using the results of tests on laterally loaded reinforced concrete beams.

Comparisons between the predicted and measured response for a number of different beam configurations show that the model is able to reproduce the physical behavior of the beams very well. If the shear span of the beam is short, or if the compression reinforcement buckles, the predictions are inferior but still reasonable.

● **6.12-129** Preiss, K., **Checking the topological consistency of a finite element mesh,** *International Journal for Numerical Methods in Engineering,* **14**, *12,* 1979, 1805–1812.

Algorithms are described for checking the topological consistency of two- or three-dimensional meshes. Two-dimensional meshes may include mixtures of triangles, quadrilaterals, and other polygons with optional edge or centre nodes; three-dimensional meshes may include mixtures of cuboids and tetrahedra with optional edge, side, or internal nodes.

● **6.12-130** Argyris, J. H., St. Doltsinis, J. and Willam, K. J., **New developments in the inelastic analysis of quasistatic and dynamic problems,** *International Journal for Numerical Methods in Engineering,* **14**, *12,* 1979, 1813–1850.

The computational aspects are examined for the numerical analysis of inelastic structures and continua. In this context, the tracing of quasistatic and dynamic motions is considered with particular emphasis on the interaction of nonlinear and transient problems. In the first part, explicit and implicit solution schemes are developed for the numerical integration of inelastic first-order rate processes governing creep, viscoelasticity, and viscoplasticity. In the second part, the exposition is extended to second-order inertial problems and in particular to the field of dynamic plasticity, devoting special attention to the kinematics of finite deformation problems.

● **6.12-131** Gupta, K. K., **Finite dynamic element formulation for a plane triangular element,** *International Journal for Numerical Methods in Engineering,* **14**, *10,* 1979, 1431–1448.

The higher order dynamic correction terms for the stiffness and inertia matrices associated with a triangular plane stress-strain finite dynamic element are developed in detail. Numerical results presented indicate that the adoption of these matrices along with a suitable quadratic matrix eigenproblem solver effects a significant economy in the free vibration solution of structures when compared with the analysis based on the usual finite element procedure. A FORTRAN IV computer program listing of the various relevant element matrices is also presented in an appendix.

● **6.12-132** Kelly, J. M. and Sackman, J. L., **Conservatism in summation rules for closely spaced modes,** *UCB/EERC-79/11,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 34. (NTIS Accession No. PB 301 328)

It is shown that the method recommended by the U.S. Nuclear Regulatory Commission to be used to combine spectral response in the case of closely spaced modes is unnecessarily conservative for certain systems. Closely spaced modes arise in structures from symmetry and where there is a light appendage with a frequency close to one of the natural frequencies of the structure. In the former case, the closely spaced modes do not interact and the Nuclear Regulatory Commission Guide is reasonable. The latter case, that is when there are closely spaced modes where interaction occurs as in the example of light appendages and in torsionally unbalanced buildings, must be treated by consideration of the interacting system. The approach proposed in this paper is that the modes which are not closely spaced be treated by modal analysis and the closely spaced modes, in the case of two closely spaced modes be treated as a coupled two degree-of-freedom system. If this is done, the beat phenomenon, the most important characteristic of the interaction between the two closely spaced modes, is evident, as is the associated result that the peak response of the coupled system is developed much later than the peak responses obtained in the individual modes by standard analysis. It is shown that the square root of the sum of the squares procedure underestimates, as expected, the response for undamped and very lightly damped systems; but, for damped systems, the square root of the sum of the squares method can be extremely conservative. It follows that the other methods specified by the Nuclear Regulatory Commission for closely spaced modes must be even more conservative.

● **6.12-133** Bhatti, M. A., Polak, E. and Pister, K. S., **OPTDYN—A general purpose optimization program for problems with or without dynamic constraints,** *UCB/EERC-79/16,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 92. (NTIS Accession No. PB 80 167 091)

This report presents a general purpose optimization program for problems with or without dynamic (also called functional) constraints, such as those arising in the design of dynamically loaded structures and in the design of controllers for linear multivariable systems using frequency response techniques. The program is based on an algorithm of the feasible directions type; a short description is included. It is written in FORTRAN IV language and runs on a CDC 6400 computer. A detailed description of the logic of the main program and instructions for writing the user-supplied subroutines to define a particular problem are included. Three sample problems chosen from different fields are given to clarify the use of the program. Listings of the main program and user-supplied subroutines for two of the sample problems are given in the appendixes.

● **6.12-134** Mondkar, D. P. and Powell, G. H., **ANSR-II: Analysis of nonlinear structural response: user's manual,** *UCB/EERC-79/17,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 88. (NTIS Accession No. PB 80 113 301)

ANSR is a general purpose computer program for the static and dynamic analysis of nonlinear structures, including both large displacements and inelastic effects. In two previously published reports, the theoretical formulations, features, and organization of version I (ANSR-I) of the program were documented. This report describes an extended version of the program (ANSR-II). Several features have been added to the program. The most important of these are (1) a comprehensive restart option; (2) provision to allow static and dynamic analyses in any sequence; (3) provision for static analysis with prescribed nodal displacements as well as nodal loads; (4) provision for out-of-phase support motions to be specified for earthquake analysis; (5) provision for time delay (traveling wave) effects to be specified for forces and displacements in dynamic analyses; and (6) out-of-core solvers for both symmetrical and unsymmetrical equations. The procedure for adding new elements to the program is described in this report, and a user's manual for the main program is given. The elements in the element library of the program will be described in separate reports.

● **6.12-135** Row, D. G., Powell, G. H. and Mondkar, D. P., **2D beam-column element (type 5-parallel element theory) for the ANSR-II program,** *UCB/EERC-79/30,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 31. (NTIS Accession No. PB 80 167 224)

This report describes a two-dimensional inelastic beam-column element developed for the ANSR-II program. The report contains a description of the element characteristics and the computer program user's guide.

● **6.12-136** Riahi, A., Powell, G. H. and Mondkar, D. P., **3D beam-column element (type 2-parallel element theory) for the ANSR-II program,** *UCB/EERC-79/31,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 33. (NTIS Accession No. PB 80 167 216)

This report describes a three-dimensional inelastic beam-column element developed for the ANSR-II program. The report contains a description of the element characteristics, the theoretical formulation, and a computer program user's guide.

● **6.12-137** Mondkar, D. P. and Powell, G. H., **3D truss bar element (type 1) for the ANSR-II program,** *UCB/EERC-79/29,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 16.

This report describes a three-dimensional, inelastic, large displacement truss element developed for the ANSR-II program. The report contains a description of the element characteristics and a computer program user's guide.

● **6.12-138** Peters, F. J., **On the implementation of an application oriented software system,** *International Journal for Numerical Methods in Engineering,* **14,** *10,* 1979, 1477–1497.

Tools for use when implementing an application-oriented software system are presented. FEMSYS, a system for calculations based on the finite element method, serves as an example. Features of a simple problem-oriented language and its parsing are discussed. Also discussed is a generally applicable data structure for both internal and external data storage. The paper indicates how a system

● *See **Preface,** page v, for availability of publications marked with dot.*

suitable for the solution of both standard and nonstandard problems can be implemented.

6.12-139 Levshin, A. L. et al., **Spectral time analysis of SVAR response** (Spektral'no-vremennoi analiz reaktsii SVAR, in Russian), *Voprosy inzhenernoi seismologii, 19,* 1978, 78-87.

A method for the spectral-time analysis of oscillator vibrations (SVAR) and an associated algorithm are described. Examples are given illustrating the potentialities of the method for solving various problems in engineering seismology, such as calculation of the response of tall flexible structures with small damping constants and dimensions commensurate with or greater than the length of a seismic wave.

● **6.12-140** Blejwas, T. and Bresler, B., **Damageability in existing buildings,** *UCB/EERC-78/12,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1979, 86. (NTIS Accession No. PB 80 166 978)

Relative hazard is evaluated by a method based on the concept of damageability, where damageability is defined as the level of damage that would occur to a building if it were exposed to a single natural hazard or a series of such hazards. The procedure developed in this paper comprises three evaluations. First, a structural response analysis is conducted; for seismic response analysis, a variation on available elastoplastic or piecewise-linear analyses is developed. The damageability of a structure is then defined as a function of intensity of exposure; for seismic damageability, generalized displacement, or base shear may be used as a measure of intensity. Local damageability indices, determined for elements throughout the structure, are combined to form a global damageability index, i.e., an index that represents the damageability of the structure as a whole. Finally, seismic damageability of the structure is related to potential earthquake demand by inelastic response spectra. The force-displacement relationship for the equivalent single degree of freedom system assumed for the quasi-static response analysis is compared to inelastic force-displacement curves from inelastic response spectra. The level of response for this equivalent system that corresponds to the particular spectrum is estimated. A third damageability index, cumulative damageability, is defined as a measure of cumulative damage to a structure from previous loadings, such as earthquake or fire loads.

● **6.12-141** Axley, J. W. and Bertero, V. V., **Infill panels: their influence on seismic response of buildings,** *UCB/EERC-79/28,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1979, 205. (NTIS Accession No. PB 80 163 371)

The problem of modeling the stiffness contribution of infill panels to elastic frame-infill systems is discussed. A set of dimensionless parameters is developed that is sufficient to define the nature of this stiffness contribution. A method for modeling the structural behavior of frame-infill systems is proposed wherein it is assumed that the primary structural system (the frame) constrains the form of the deformation of secondary structural elements (the infill panels). It is suggested that such a constraint approach may be considered to be generally useful in modeling the behavior of certain classes of secondary structural elements. This constraint approach, as developed in this paper, is an approximate finite element substructuring technique that has the effect of reducing the analytical complexity of frame-infill systems and leads naturally to the development of a group of computationally attractive 12 degree-of-freedom infill elements that may simply be "plugged" into conventional frame analysis programs. Four infill elements are presented corresponding to completely and partially infilled frames with complete and partial constraint assumptions considered. Other possible elements are discussed briefly. The suitability and accuracy of the constraint approach is evaluated.

These infill elements are then utilized in a detailed three-dimensional elastic analysis of a building that suffered extensive damage during the Feb. 1976 Guatemalan earthquake. The nature of the response of this building to seismic excitation is considered and the influence of the infill upon this response is discussed in detail.

● **6.12-142** Lew, T. K. and Takahashi, S. K., **Rapid seismic analysis procedure,** *Technical Memorandum 51-78-02,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Apr. 1978, 140.

It is well known that man-made structures are susceptible to earthquake damage, especially from major earthquakes. In addition to the potential monetary loss, the damage of naval installations from earthquakes can contribute to the loss of operative capacity and life hazard. The rapid analysis procedure presented in this paper provides an overall estimate of damage to an installation when the site is subjected to a potential earthquake. Although the procedure presented was originally developed for the seismic study of Puget Sound Naval Shipyard, it has been modified and adapted for seismic studies at three naval stations in California. The major modifications that have been made are a systematization of the analysis of the facility inventory assets at a naval installation and the development of the response spectra for the design earthquakes. In addition, several phases have been automated, including the computation of the shear stiffnesses for concrete or masonry buildings, the computation of the first mode shape and the natural period of a multistory building, and the estimation of building damage from the response spectra. The major steps involved in the analysis procedure are (1) selection of buildings, (2) determination of response spectra for the design earthquakes, (3) estimation of yield and ultimate capacities, (4) estimation of natural periods, and (5) estimation of damage from the response spectra for peak ground accelerations from 0.05 g to 0.50 g. With very little modification, the rapid seismic analysis procedure can be used to evaluate the potential earthquake damage to buildings at other military or government installations with a large number of buildings.

● **6.12-143** Cheng, F. Y. and Kitipitayangkul, P., **Investigation of the effect of 3-D parametric earthquake motions on stability of elastic and inelastic building systems,** *Report 1, Civil Engineering Study, Structural Series 79-10,* Dept. of Civil Engineering, Univ. of Missouri, Rolla, Aug. 1979, 357.

An analytical study is presented for the purpose of investigating the effect of interacting three-dimensional ground motions on the response behavior of elastic and inelastic building systems. The building systems may have elevator cores, floor diaphragms, and shear walls of reinforced concrete as well as steel beams, columns, and bracings. The stiffness matrices are derived from the Ramberg-Osgood hysteresis for steel and Takeda's model for concrete. The geometric matrix is formulated for the second-order effect on large deflections. The interacting forces on the yielding surfaces of the members are included.

A comprehensive computer program, INRESB-3D, has been developed for achieving efficiency in both computation and data preparation. (See Abstract No. 6.12-144 for a description of the program.) A total of 26 numerical examples have been studied for various lowrise and highrise building systems, which show that an interacting ground motion can significantly increase internal forces, nodal displacements, ductilities, and seismic input and dissipated energy. The large ductilities and the excessive permanent deformations induced by a coupling motion exhibit severe local damage and thus diminish the serviceability of a structure.

● **6.12-144** Cheng, F. Y. and Kitipitayangkul, P., **INRESB-3D: a computer program for inelastic analysis of reinforced-concrete steel buildings subjected to 3-dimensional ground motions,** *Report 2, Civil Engineering Study, Structural Series 79-11,* Dept. of Civil Engineering, Univ. of Missouri, Rolla, Aug. 1979, 97.

This report has been prepared as a user's guide for the computer program, INRESB-3D, for analyzing elastic and inelastic building systems subjected to the simultaneous input of static loads and multicomponent earthquake motions, which can be applied in any direction of the structural plane. The building systems may have elevator cores, floor diaphragms, and shear walls of the reinforced concrete, as well as steel beams, columns, and bracings. The stiffness matrices are derived from the Ramberg-Osgood hysteresis for steel and Takeda's model for concrete. The geometric matrix is formulated for large deflections by considering the second-order effect on the bending moments. The interacting forces on the yielding surfaces of the members are included. The computer program has been comprehensively developed for achieving efficiency in both computation and data preparation. The output solutions include the static results of member forces and nodal displacements as well as the dynamic results of member forces, nodal displacements, ductility factors, excursion ratios, seismic input energies, dissipated energies, and the options of plotting some of the dynamic results. The main features of the report include the program list, a description of the program, instructions for data preparation, and a guide to modify the program's capacity.

● **6.12-145** McGuire, W. and Gallagher, R. H., **Matrix structural analysis,** John Wiley & Sons, New York, 1979, 460.

This book contains chapters on the following subjects: definitions and concepts of terminology in the field of matrix structural analysis; formation of global analysis equations; stiffness analysis of frames; static and kinematic equations; the flexibility method; virtual work principles in general and for framework analysis; special analysis procedures, such as condensation, substructuring, and reanalysis techniques; solution of linear algebraic equations; and the finite element method. Also included are author and subject indexes.

● **6.12-146** Al-Mahaidi, R. S. H., **Non-linear finite element analysis of reinforced concrete deep members,** *79-1,* Dept. of Structural Engineering, Cornell Univ., Ithaca, New York, Jan. 1979, 374.

The purpose of this investigation is the analysis of deep reinforced concrete members in the linear, nonlinear, and ultimate ranges. The finite element method is utilized to study the behavior of these members under monotonically increasing loads. All the major factors causing material nonlinearity are considered. Primary consideration is given to the representation of shear transfer mechanisms, which are a result of aggregate interlock in cracked concrete, and to dowel action in reinforcement. Expressions are derived from an analytical model in conjunction with experimental data to provide shear stress and stiffness values for special elements used to model the aggregate interlock mechanism. These are expressed as functions of the crack width, concrete strength, and shear displacement. A comparable approach is used to derive expressions for the dowel action mechanism. These are expressed in terms of the reinforcement diameter, yield strength, dowel displacement, and crushing strength of concrete.

● *See **Preface**, page v, for availability of publications marked with dot.*

Improved isoparametric quadrilateral and triangular elements are used to represent the concrete. Material response is assumed to be orthotropic with tangent stiffnesses E_1 and E_2 derived from a stress-strain relation for concrete under a general biaxial state of stress. Two methods of crack representation are used: the distributed cracking approach and the discrete cracking approach. The reinforcement is represented in a discrete manner. One-dimensional flexural and axial elements are used for this purpose. Material response is assumed to be elastic-perfectly plastic. The bond-slip phenomenon between the concrete and the reinforcement is accounted for by using nondimensional spring elements. Stiffness values for such elements are obtained from expressions based on experimental data. The nonlinear problem is solved by using an incremental iterative numerical method. Each load increment is followed by iterations to bring the amount of equilibrium violation to a tolerable limit. A computer program has been developed to perform the nonlinear analysis using the constitutive relations and the solution strategy mentioned above.

The validity of the proposed analytical model is assessed by analyzing three experimental deep members. As a result of the analyses, it is concluded that the suitability of the distributed cracking method is restricted to reinforced concrete members which develop minor cracks. The use of a combined distributed-discrete cracking approach is found to be successful in analyzing members which develop major as well as minor cracks. This proved to be necessary if realistic predictions of the distribution of internal stresses and the contribution of aggregate interlock and dowel action shear resistance mechanisms are desired. Some discrepancies, however, have been found between the experimental and analytical crack patterns. This is primarily a result of the inherent characteristics of the distributed cracking approach.

● **6.12-147** Bathe, K.-J. et al., **SAP IV-B—Description and user manual: a system of programs for the linear static and dynamic calculation of structures** (SAP IV-B—Beschreibung und Benutzerhandbuch ein Programmsystem zur linearen statischen und dynamischen Berechnung von Tragwerken, in German), 3rd extended ed., *79-3*, Inst. fur Konstruktiven Ingenieurbau, Ruhr-Univ. Bochum, Bochum, West Germany, Mar. 1979, 219.

● **6.12-148** Crisfield, M. A., **Iterative solution procedures for linear and non-linear structural analysis**, *TRRL Laboratory Report 900*, Transport and Road Research Lab., Great Britain Depts. of the Environment and Transport, Crowthorne, 1979, 35.

Three iterative solution procedures are reviewed: the variable metric method, the conjugate gradient method, and dynamic relaxation. As a result of this review, a "secant iterative method" is proposed which is related to both the variable metric and the conjugate gradient techniques. The secant method is better suited to structural analysis and may be used as an accelerated modified Newton-Raphson method for nonlinear analysis. It may also be used in conjunction with a subdivided coarse mesh/fine mesh structural idealization. In its latter form, it could be used for linear or nonlinear analysis.

● **6.12-149** Bathe, K.-J., Clough, R. W. and Wilson, E. L., **Lecture notes for finite element analysis: formulations and computational procedures in static and dynamic analysis**, Seminar held Sept. 4-6, 1978, in Paris, Inst. pour la Promotion des Sciences de l'Ingenieur, Paris, 1978, 570.

● **6.12-150** Ballio, G., Gobetti, A. and Zanon, P., **Analytical computations of dynamic behaviour of pin jointed structures**, *Environmental Forces on Engineering Structures*, 459-472. (For a full bibliographic citation, see Abstract No. 1.2-28.)

● **6.12-151** Collings, A. G. and Saunders, L. R., **Interpolation-based methods for the efficient determination of the dynamic responses of linear structural systems**, *Environmental Forces on Engineering Structures*, 439-458. (For a full bibliographic citation, see Abstract No. 1.2-28.)

6.12-152 Kotsubo, S., Uno, K. and Sonoda, T., **Response analysis of bridge for propagating earthquake waves by using response spectrum**, *Transactions of the Japan Society of Civil Engineers*, **10**, Nov. 1979, 16-17. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 270*, Feb. 1978, 51-58.)

This paper describes a method for the response analysis of bridges by using a response spectrum when the seismic wave propagates at each support of the bridges with a phase delay. In this analysis, it was assumed that the propagating velocity of the wave is uniform in all frequencies.

6.12-153 Ishikawa, N., Ohno, T. and Okamoto, K., **A study on the optimal plastic design of space frames**, *Transactions of the Japan Society of Civil Engineers*, **10**, Nov. 1979, 95-97. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 279*, Nov. 1978, 45-59.)

This paper presents a linear programming (LP) approach to the optimal plastic design of space frames under combined stresses. The method first adopts the approximate piecewise-linear yield modes expressed in the dimensionalized form. Then, matrix algebra techniques applied to a frame element are employed to derive the conditions of equilibrium and mechanism, and to develop the dual static and kinematic LP statements of the minimum weight design. Furthermore, LP decomposition techniques are introduced with a view to numerical efficiency. Three

● *See **Preface**, page v, for availability of publications marked with dot.*

examples illustrate the features and the scope of application of the approach. All assumptions based on the rigid-plastic theory are explicitly used. It is assumed that the ratios among the plastic capacities of each element remain constant and that the weight per unit length of each element is a linear function.

● **6.12-154** Marmarelis, V. Z. et al., **Analytical and experimental studies of the modeling of a class of nonlinear systems,** *Nuclear Engineering and Design,* **55,** *1,* Dec. 1979, 59-68.

This paper deals with the identification of complex structural and mechanical systems often encountered in the nuclear industry. Nonparametric identification techniques are used to analyze the response of a class of nonlinear components. Efficient computational algorithms and experimental techniques based on such nonparametric system identification methods as the Wiener-kernel approach and least-squares regression techniques involving system state variables are developed and applied to an example system. The variation of system signature with its change in characteristics is studied and the effects of various parameters of the excitation, system, and the computation algorithm on the signature analysis are investigated. The use of the methods for the modeling of realistic systems is evaluated and found to be promising. It appears that the methods may be useful for the damage assessment of critical facilities such as nuclear reactors.

● **6.12-155** Gordis, K., **Outline of dynamic analysis for piping systems,** *Nuclear Engineering and Design,* **52,** *1,* Mar. 1979, 99-110.

The paper examines mathematically a number of theoretical and practical problems involved in the solution of dynamic structural problems by means of the modal superposition method. In particular, problems related to piping system structures subjected to single- or multi-level support movement loading are treated.

● **6.12-156** Alesso, H. P., **Elementary catastrophe theory modelling of Duffing's equation for seismic excitation of nuclear power facilities,** *Nuclear Engineering and Design,* **52,** *1,* Mar. 1979, 145-155.

Elementary catastrophe theory (ECT) can provide conceptual insight into some aspects of a variety of problems in dynamics. It is a qualitative tool that provides an avenue for quantitative analysis. In this paper, it is used to study the forced nonlinear vibrations of seismic disturbances, which may be approximated by Duffing's equation. The behavior of such a system fits naturally into ECT modeling, where changes in parameters of the system lead to jump-type behavior. The important conclusion is that nonlinear oscillators can exhibit the characteristics of elementary catastrophes, but the design engineer may be able to manipulate characteristics of the system in order to avoid the jump behavior of the response.

● **6.12-157** Wang, W. Y., Wang, P. C. and Abdelrahman, A. M., **Effective duration of seismic acceleration and occurrence of maximum responses,** *Nuclear Engineering and Design,* **52,** *1,* Mar. 1979, 165-174.

The maximum response of structures subjected to a seismic excitation is generally obtained by means of a dynamic analysis, using the entire history of an accelerogram. However, because of the damping effect of structures, only a certain portion of the accelerogram is effective and contributes significantly to the peak response. This paper introduces an efficient procedure for separately selecting the effective duration from a seismic excitation and predicting the occurrence time of the response maxima. An analytical procedure is developed to determine the effective duration for a seismic excitation, based on the study of the structural responses and the control on the error bound. Three multidegree-of-freedom structures are subjected to several accelerograms with the results obtained proving the accuracy of the procedure. The occurrence of the response maxima is derived analytically for the two extreme cases of structural rigidity, namely very flexible structures (e.g., tall stacks) and very rigid structures (e.g., nuclear reactors). For structures with intermediate rigidity, the response resulting from the application of various actual accelerograms indicates the correlation between the response maxima and the arrival frequency of seismic waves.

6.12-158 Seniwongse, M., **The deformation of reinforced concrete beams and frames up to failure,** *The Structural Engineer,* **57B,** *4,* Dec. 1979, 77-81.

A beam-rotational spring model is presented for the nonlinear analysis of reinforced concrete structures subjected to monotonically increased or reversed static loading. A beam or frame is treated as an assembly of beam elements. Each beam element has a bilinear hysteretic rotary spring at each end. The beam elements are assumed to remain elastic in bending along their length, but may undergo inelastic bilinear hysteretic axial deformation.

A computer program NLACF (Non-Linear Analysis of Concrete FRame) based on the proposed model has been developed in FORTRAN IV language. The use of the program to predict the load-deformation and ultimate strength of reinforced concrete structures is illustrated by application to a simply supported reinforced concrete beam and three reinforced concrete frames. Comparison of the results with the results reported by other investigators indicates that the ultimate strength of a reinforced beam or frame can be accurately predicted by the proposed beam-rotational spring model, maximum discrepancy being of the order of 3%. It is concluded that the proposed model

● *See* ***Preface****, page v, for availability of publications marked with dot.*

provides a simple but accurate analytical tool for predicting the ultimate strengths of reinforced concrete structures.

● **6.12-159** Ikushima, T. and Nakazawa, T., **A seismic analysis method for a block column gas-cooled reactor core,** *Nuclear Engineering and Design,* **55,** *3,* Dec. 1979, 331–342.

An analytical method for predicting the behavior of a prismatic high-temperature gas-cooled reactor (HTGR) core under seismic excitation has been developed. In this analytical method, blocks are treated as rigid bodies which are constrained by dowel pins to restrict relative horizontal movement but allow vertical and rocking motions. Coulomb friction between blocks and between dowel holes and pins is also considered. A spring dashpot model is used for the collision process between adjacent blocks and between blocks and boundary walls. Analytical results are compared with experimental results and are found to be in good agreement.

● **6.12-160** McVerry, G. H., **Frequency domain identification of structural models from earthquake records,** *EERL 79-02,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Oct. 1979, 213.

The usefulness of simple linear mathematical models for representing the behavior of tall buildings during earthquake response is investigated for a variety of structures over a range of motions including the onset of structural damage. The linear models which best reproduce the measured response of the structures are determined from the recorded earthquake motions. In order to improve upon unsatisfactory results obtained by methods using transfer functions, a systematic frequency domain identification technique is developed to determine the optimal models. The periods, dampings, and participation factors are estimated for the structural modes which are dominant in the measured response.

The identification is performed by finding the values of the modal parameters which produce a least-squares match over a specified frequency range between the unsmoothed, complex-valued, finite Fourier transform of the acceleration response recorded in the structure and that calculated for the model. It is possible to identify a single linear model appropriate for the entire response, or to approximate the nonlinear behavior exhibited by some structures with a series of models optimal for different segments of the response. The investigation considered the earthquake records obtained in ten structures ranging in height from seven to forty-two stories. Most of the records were from the San Fernando earthquake. For two of these structures, smaller-amplitude records from more distant earthquakes were also analyzed. The maximum response amplitudes ranged from approximately 0.025 g to 0.40 g. The very small amplitude responses were reproduced well by linear models with fundamental periods similar to those measured in vibration tests. Most of the San Fernando responses in which no structural damage occurred (typically 0.2 g-0.3 g maximum accelerations) were also matched closely by linear models. However, the effective fundamental periods in these responses were characteristically 50 percent longer than in vibration tests. The average first mode damping identified from these records was about 5 percent of critical. Only those motions which produced structural damage could not be represented satisfactorily by time-invariant linear models. Segment-by-segment analysis of these records revealed effective periods of two to three times the vibration test values with fundamental mode dampings of 15 to 20 percent.

The systematic identification technique generally achieves better matches of the recorded responses than those produced by models derived by trial-and-error methods, and consequently more reliable estimates of the modal parameters. The close reproductions of the measured motions confirm the accuracy of linear models with only a few modes for representing the behavior during earthquake response of tall buildings in which no structural damage occurs.

● **6.12-161** Ove Arup and Partners, **DAFT: a dynamic analysis computer program** [London, 1978], 10.

This dynamic analysis program has been developed under the sponsorship of the U.K. Dept. of Energy. DAFT is an acronym for Dynamic Analysis using Fourier Transforms. The program is a powerful dynamic analysis tool which can consider two- or three-dimensional models of structures on land or in water. The structures can be situated on various types of support, and can be subjected to various types of dynamic loading such as earthquakes and wave loadings. One of the major features of the program is that it can analyze soil-structure systems allowing for radiation damping in the soil; this phenomenon is handled using a frequency-dependent formulation of the soil treated as a halfspace. Fourier transforms are involved.

● **6.12-162** Petrangeli, M. P., **Approximate calculation of a bridge pier in a seismic zone** (Calcolo approssimato delle pile dei ponti a travata in zona sismica, in Italian), *Giornale del Genio Civile,* **117,** *10/12,* Oct.-Dec. 1979, 349–357.

A method based on simple theoretical considerations is proposed for the dynamic calculation of bridge piers. The method, which can be calculated by hand, permits the evaluation of forces resulting from a given acceleration spectrum. An example for piers with constant cross sections shows that the results obtained with the method almost approximate those of classic modal analysis.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

6.13 Nondeterministic Methods of Dynamic Analysis

● **6.13-1** Chakravorty, M. K., Wong, A. Y. C. and Foster, D. C., **Probabilistic prediction of floor response spectra,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 445–464.

A simplified probabilistic method of seismic analysis is reviewed, and its application to floor response spectra generation is demonstrated using an example seismic analysis of a nuclear power plant structure founded on soil. The earthquake input is represented as a limited-duration, stationary random process with a power spectral density function derived from the USNRC design response spectrum. In addition, a Kanai-Tajimi spectral density shape function is studied as a representation of earthquake input. The results of the random vibration approach are compared with those of the time history method. It is seen that the probabilistic method provides an adequate estimate of the floor response spectra for design purposes and requires less computational effort than time history methods, thus enabling one to economically perform various parametric studies and reduce overall analysis costs.

● **6.13-2** Aziz, T. S. and Biswas, J. K., **Spectrum-compatible time-histories for seismic design of nuclear power plants,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 301–324.

The current practice for the seismic design of nuclear power plant (NPP) structures and components is to utilize a design basis response spectrum which represents an envelope of possible ground motion effects on a series of one degree-of-freedom oscillators. In order to apply the time history method of seismic analysis to the design of NPP structures and components, it is often necessary to generate an artificial time history from a given design response spectrum. The only criteria currently used in the industry which appears to be acceptable to most regulatory authorities is that the generated time history spectrum must envelope the design response spectrum. When it is required to excite the mathematical models with two-dimensional or three-dimensional seismic motions, an additional criterion has emerged, the statistical independence between the different motion components. While these criteria have never posed any practical problems, it is believed that very little is known about the different variables, the alternatives associated with the generation process, and the impact of these variables and alternatives on the final response of the structure or the equipment housed inside the structure.

In this paper, a state-of-the-art review of the different methods available for developing spectrum-compatible time histories is presented. Two independent approaches have been utilized to generate two spectrum-compatible time histories. One approach is deterministic in nature; the other is based on random vibration theory. The two resulting time histories were tested for compatibility and used for the seismic analysis of a typical CANDU 600 MWe reactor building. Response quantities such as accelerations, displacements, overturning moments, and shear forces were computed. Responses were also computed using the conventional response spectrum method. Comparisons of results obtained using the different methods were made and discussed. It is concluded that properly generated time histories generally yield comparable seismic response.

● **6.13-3** Webster, F. A. and Benjamin, J. R., **Analysis of multiple degree of freedom systems with correlated and uncertain response spectra parameters,** *Proceedings of the 2nd U. S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 505–514.

A new data-based response spectra model is introduced which summarizes response spectra data with a mean value function and a measure of variability. Parameters of the model are found to be correlated from one earthquake record to the next at a specific site. A multivariate probabilistic model with dependent variables is introduced for site-specific response spectra criteria. Two example multidegree-of-freedom structures are analyzed by response spectra modal analysis to compare conventional criteria with the proposed model.

● **6.13-4** Harris, C. J., **Simulation of multivariable nonlinear stochastic systems,** *International Journal for Numerical Methods in Engineering,* 14, *1,* 1979, 37–50.

An important step in the modeling of dynamic systems is the validation of the assumed model equations with experimental data or observations of the actual system. If physical reasoning leads to models described by either nonlinear or partial differential equations, analytical or closed-form solutions are, in general, extremely complex and recourse is made to either simulation or numerical approximation techniques. Any inadequacy of the modeling process resulting from either lack of physical insight or the representation of distributed parameter systems by lumped parameter models can be conveniently represented by introducing random perturbations in either the model inputs or in the model parameters. The resulting equations are suitable for describing a wide variety of complex engineering, econometric, and biological systems. Stochastic variations in model parameters occur, for example, in the propagation properties of transmission channels or in control systems subject to unpredictable environmental variations such as occur in wastewater treatment plants and

● *See **Preface**, page v, for availability of publications marked with dot.*

in satellite attitude control. In some control applications, this stochastic element can be produced by round-off and quantization error, or by the presence of the human operator in the control loop. Parametric excitation also arises naturally in studies of the dynamic stability of elastic structures which exhibit a bifurcation form of stability under applied loads. The distinguishing feature is that the external load appears in the governing differential equations in the form of coefficients. Examples include flutter and vibration in panels/plates excited by pressure fluctuations in turbulent boundary layers and in simply supported elastic beams subjected to dynamic transverse loads. The above applications lead to mathematical models in which the stochastic processes enter the model in a multiplicative manner and not in an additive way, as in the case of the classical Wiener and Kalman-Bucy filtering problem.

● 6.13-5 Kajimura, Y. and Shiraki, K., **Statistical method estimating the seismic response of light secondary systems,** *Engineering Design for Earthquake Environments,* Paper No. C191/78, 207–214. (For a full bibliographic citation, see Abstract No. 1.2–2.)

The response of light secondary systems to strong-motion earthquakes is considered. Secondary systems may include light mechanical equipment, piping or other light systems attached to floors of the primary supporting structure. Within the framework of the normal mode method, a stationary random vibration approach to the response prediction of such secondary systems is developed. The accuracy of this proposed method is verified by comparing the calculated responses with the average of the time-history solution. It is shown that the method is effective for the calculation of floor response spectra and the response of multiply supported secondary systems.

● 6.13-6 Zbirohowski-Koscia, K. F., **On the probabilistic prediction of seismic response,** *Engineering Design for Earthquake Environments,* Paper No. C183/78, 157–168. (For a full bibliographic citation, see Abstract No. 1.2–2.)

A probabilistic method is proposed for the assessment of dynamic response to earthquake ground movements. The statistics of the normalized PSD (power spectrum density) functions imply that the dynamic response can be expressed as a product of a deterministic value and two or more independent variables. The approximate shape of the standard PSD curve for obtaining this deterministic value was derived from 21 records of seismic events in the United States. The time history responses to the same records for 16 single degree-of-freedom systems provided the statistical data used to fit two PDFs (probability density functions) of the two out of three random variables required for the analysis. It was found that a log-normal distribution PDF fitted these statistical data quite well.

● 6.13-7 Zeman, J. L., **The superposition problem of the response spectrum technique,** *Engineering Design for Earthquake Environments,* Paper No. C172/78, 23–26. (For a full bibliographic citation, see Abstract No. 1.2–2.)

The problem usually encountered with the response spectrum approach in the case of multidegree-of-freedom systems is shown and discussed by means of various examples. An approach for overcoming this difficulty, based on results of the theory of stochastic processes, is outlined and illustrated in two examples.

● 6.13-8 Larrabee, R. D. and Cornell, C. A., **Upcrossing rate solution for load combinations,** *Journal of the Structural Division, ASCE,* **105,** *ST1,* Proc. Paper 14329, Jan. 1979, 125–132.

An exact expression for the mean upcrossing rate of a sum of two Poisson square-wave process representations of stochastic loading functions is used to explore the accuracy of Wen's approximation of the extreme value distribution of such processes. The approximation is found to be accurate over a broad parameter range despite the fact that it ignores the randomness of load durations and implicitly assumes very infrequent load events. The limits of the mean upcrossing rate as an approximation to the extreme value distribution are also studied.

● 6.13-9 Lutes, L. D. and Lilhanand, K., **Frequency content in earthquake simulation,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM1,* Proc. Paper 14391, Feb. 1979, 143–158.

Random processes with a frequency content similar to that of recorded earthquakes are generated by using linear filters to remove the very low and very high frequency components of white noise. The mean-squared responses of single degree-of-freedom structures to these filtered processes are compared with the corresponding responses to white noise excitation. For linear structures, exact analytical solutions for mean-squared displacement and velocity response are presented. Using an "equivalent" white noise to approximate the nonwhite noise excitation generally extends the frequency range of adequate approximation, particularly for small structural damping. For yielding structures, Monte Carlo simulation is used to obtain response levels for some representative situations. The effect of a second-order filter on yielding system response is somewhat different than for a linear system; in fact, it is more like the effect of a first-order filter on linear system response.

● 6.13-10 Contreras, H., **Step-by-step integration of linear structural systems considering uncertainty in the parameters,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 525–532.

Using a new approach to account for the main sources of uncertainty in the dynamic analysis of structures, this paper presents a generic stochastic finite-element method for modeling structures. Stochastic differential and difference equations are combined with the finite-element method so that loads for structures are idealized as stochastic processes and are incorporated into multidimensional finite-element dynamic models with uncertainty in their parameters.

● **6.13-11** Larrabee, R. D., **Approximate stochastic analysis of combined loading,** *Research Report R78-28,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Sept. 1978, 178.

A simple, unified formulation for the probabilistic combination of structural loads (the point-crossing method) is based on finding the mean upcrossing rate of the sum of independent, individual load processes. Each random process is characterized by only two line-invariant functions: the arbitrary point-in-time probability distribution and the mean upcrossing rate function. The corresponding pair of functions for the sum of two load processes can be constructed by single convolution operations on the individual load functions; multiple loads are combined by repeating the operation. It is shown that the resulting upcrossing rate estimate is exact for sums of many other renewal pulse processes and is a useable (upper bound) approximation for sums of many other renewal pulse processes and continuous, smooth processes used to model loads. Development of the point equations of a partial-factor design code is explored. Finally, some issues concerning vector-valued load effects and safe domains and selected types of dependence are investigated.

● **6.13-12** URS/John A. Blume & Assoc., **Nonlinear structural dynamic analysis procedures for Category I structures,** *NUREG/CR-0948,* San Francisco, July 1979, 288.

This report presents the results of studies conducted to identify and recommend a simplified dynamic analysis procedure applicable to the nonlinear analyses of Category I nuclear power plant structures. For the recommended simplified analysis procedure, the theoretical background, mathematical formulation, analytical solution, verification of reliability, and interpretation of results were to be established. In addition, studies were conducted to compare the results of conventional linear analysis with nonlinear analyses to establish the relative merits of the two approaches. This is a generic study dealing with the subject of nonlinear structural response. Various aspects of this study, including the structures considered, the analysis criteria, the dynamic loadings, and the material properties, are purely hypothetical. These aspects are intended to model Category I conditions, and any resemblance to specific nuclear power plant structures is purely coincidental.

The process used to identify and evaluate the applicability of a simplified nonlinear analysis procedure consisted of three main tasks. (1) A literature search was completed for both rigorous and simplified nonlinear dynamic analysis procedures applicable for Category I nuclear power plant structures. (2) Various simplified nonlinear analysis methods to identify the most pertinent yet practical procedure for Catageoy I structures were evaluated. This task also included studies and evaluations aimed at establishing analysis guidelines, reliability of the analysis, and guidelines for interpreting the results for the recommended simplified method. (3) An analysis was performed of specific benchmark problems for the purpose of comparing the rigorous and simplified analysis methods and for evaluating the relative merits of conventional elastic analysis vis-a-vis nonlinear analysis. The analysis procedures studied are general and can be applied to most types of dynamic loadings. Budget limitations for this study dictated that verification of these procedures be limited to the base-input-motion earthquake problem.

● **6.13-13** Chopra, A. K. and Lopez, O. A., **Evaluation of simulated ground motions for predicting elastic response of long period structures and inelastic response of structures,** *Earthquake Engineering & Structural Dynamics,* **7**, *4*, July-Aug. 1979, 383-402.

The response is studied of linear elastic and nonlinear hysteretic systems having a single degree-of-freedom and subjected to recorded and simulated ground motions. The objective is to evaluate whether the commonly used simulated motions are appropriate for predicting the inelastic response of structures and the elastic response of long-period structures. Eight simulated motions were generated to model properties of horizontal ground motions recorded during four earthquakes. The simulated motions are sample functions of a stationary, Gaussian white noise process, multiplied by a temporal intensity function and passed through a linear single degree-of-freedom filter. Two versions, corresponding to parabolic and standard base line corrections (BLC), of each of the simulated and recorded accelerograms were considered. The following general conclusions are deduced. Simulated ground motions should be subjected to the standard BLC, because it results in more reliable ground velocities and displacements, which in turn would lead to more reliable predictions of response of long-period structures. Furthermore, the spectral density of the underlying random process, from which the simulated motions are obtained, should be modified to be more representative of the frequency content of recorded motions, especially in the low-frequency range. Such an improved model can be expected to lead to better agreement, over a broad range of periods, in the average response spectra of simulated and recorded motions for elastic as well as inelastic systems.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **6.13-14** Fiessler, B., Neumann, H.-J. and Rackwitz, R., **Quadratic limit states in structural reliability,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM4,* Proc. Paper 14739, Aug. 1979, 661-676.

Second-moment methods are widely applied in structural reliability. Recently, so-called first-order reliability methods have been developed that are capable of producing reliable estimates of the failure probability for arbitrary design situations and distributional assumptions for the uncertainty vector. In essence, nonlinear functional relationships or probability distribution transformations are approximated by linear Taylor expansions so that the simple second-moment calculus is retained. Failure probabilities are obtained by evaluating the standard normal integral, which is the probability content of a circular normal distribution in a domain bounded by a hyperplane. In this paper, second-order expansions are studied to approximate the failure surface, and some results of the statistical theory of quadratic forms in normal variates are used to calculate improved estimates of the failure probability.

● **6.13-15** Grigoriu, M., Veneziano, D. and Cornell, C. A., **Probabilistic modeling as decision making,** *Journal of the Engineering Mechanics Division, ASCE,* **105,** *EM4,* Proc. Paper 14736, Aug. 1979, 585-596.

One of the factors that limits the application of probabilistic reliability to engineering design is the arbitrariness with which a probability distribution may be chosen. The problem is particularly severe when high reliability is demanded and information is scarce, e.g., in selecting tail probability laws for load and resistance variables. At the origin of this arbitrariness is the attempt to select models through inference procedures, i.e., solely on the basis of physical and statistical information. The problem is, by its very nature, one of decision making and should be resolved through methods of decision theory. If this is done, then a number of interesting facts emerge: (1) the optimal distribution is also defined under conditions of extreme uncertainty; (2) the optimal distribution is less sensitive to statistical sample variations than the distribution obtained by inference procedures; and (3) with limited statistical information, optimal distributions tend to err on the side of conservative design, with a degree of conservatism that decreases as the amount of information increases.

● **6.13-16** Cornell, C. A., Banon, H. and Shakal, A. F., **Seismic motion and response prediction alternatives,** *Earthquake Engineering & Structural Dynamics,* **7,** *4,* July-Aug. 1979, 295-315.

Statistical methods are available which predict the maximum response of simple oscillators given the peak acceleration, peak velocity, or peak displacement of seismic ground motions. An alternative parameter, namely an ordinate (or ordinates) of the Fourier amplitude spectrum of ground motion acceleration $FS(f)$, may in fact be a preferred predictor of peak response, especially in a frequency range close to f. Other statistical methods (attenuation laws) use distance R and other parameters such as magnitude (M), modified Mercalli epicentral intensity (I_O) and modified Mercalli site intensity (MMI or I_S) to predict spectral velocity ($S_V(f)$), etc. In using such approaches, it is most desirable to know the total uncertainty in the predicted peak response of the system given the starting parameter values. An extensive strong-motion data set is used to study these questions. Because of lower prediction dispersion, the most direct prediction models are found to be preferable, but data may not be available in all regions to permit their use.

● **6.13-17** Prasad, T. and Ibidapo-Obe, O., **The role of observations in stochastic linear dynamic models,** *Applied Mathematical Modelling,* **3,** *4,* Aug. 1979, 263-268.

This paper emphasizes the use of realistic observations for response evaluation of stochastic linear dynamic systems. A simulation study is presented to justify the approach. It is shown that the innovations approach may be used efficiently in this context. The structural model and computational algorithms are presented, and their relevance to numerous applied problems in technology and the life sciences is considered.

● **6.13-18** Cacko, J. and Bily, M., **Simulation of a nonstationary stochastic process with respect to its power spectral density,** *Journal of Sound and Vibration,* **66,** *2,* Sept. 22, 1979, 277-284.

This paper presents a method of simulation of nonstationary stochastic processes which is based on modeling their time-dependent power spectral densities. Filtering of a nonstationary white noise through a conveniently selected linear dynamic system is used. All computations required are fast enough for the simulated process to be used as the on-line input of computer-controlled loading machines.

● **6.13-19** Drenick, R. F. and Yun, C.-B., **Reliability of seismic resistance predictions,** *Journal of the Structural Division, ASCE,* **105,** *ST10,* Proc. Paper 14876, Oct. 1979, 1879-1891.

This paper explores the effect of uncertainties in information regarding ground-motion statistics during an earthquake and finds that the uncertainties are large enough to preclude sufficient confidence from being placed in many predictions of earthquake resistance. The authors recommend that the usual all-probabilistic approach be replaced with a suitable combination of probabilistic and worst-case analyses and report on a study in which this combination was explored. Based upon this study, the combined approach appears to be sufficiently successful to encourage its consideration in other studies.

● **6.13-20** Masri, S. F. and Caughey, T. K., **A nonparametric identification technique for nonlinear dynamic problems,** *Journal of Applied Mechanics, ASME,* **46**, *2*, June 1979, 433-447.

A nonparametric identification technique is presented that uses information about the state variables of nonlinear systems to express the system characteristics in terms of orthogonal functions. The method can be used with deterministic or random excitation (stationary or otherwise) to identify dynamic systems with arbitrary nonlinearities, including those with hysteretic characteristics. The method is shown to be more efficient than the Weiner-kernel approach in identifying nonlinear dynamic systems of the type considered.

● **6.13-21** Benjamin, J. R. and Webster, F. A., **Decision optimization of lifelines with multiple earthquake associated hazards,** *Lifeline Earthquake Engineering–Buried Pipelines, Seismic Risk, and Instrumentation,* 199-206. (For a full bibliographic citation, see Abstract No. 1.2-16.)

At the present time, typical analyses of lifelines for earthquake hazards do not include the possibility of correlated capacities or dependent load levels along the length of the lifeline. This paper presents a methodology for analyzing the response of a continuous lifeline system with correlated and dependent probabilistic response and load-level characteristics. It also addresses the question of possible multiple hazards from the same earthquake.

An example levee problem is first solved using a discrete analysis, and then the solution is extended to a closed-form continuous model. For anything but a very simple problem, the discrete form analysis becomes intractable, and, for this reason, the continuous closed-form solution was developed. The discrete analysis, however, has the advantage of being able to show the linkages between possible outcomes. Various methods, such as testing, modeling, and expert opinion, are suggested for determining correlations and levels of dependence.

● **6.13-22** Gurpinar, A., **Introduction to statistical methods in engineering–volume I,** Dept. of Engineering Sciences, Middle East Technical Univ., Ankara, 1979, 182.

The purpose of this volume is to convey to the engineering student the rudimentary principles of the theory of probability and statistics with applications. Contained in the volume are chapters on descriptive statistics, basic probability concepts, random variables, and inductive statistics.

● **6.13-23** Chou, C. K., Lo, T. Y. and Vagliente, V. N., **Major structural response methods used in the Seismic Safety Margins Research Program,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 3/7, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In order to evaluate the conservatism in present nuclear power plant seismic safety requirements, a probabilistic-based systems model is being developed. This model will also be used to develop improved requirements. In Phase I of the Seismic Safety Margins Research Program (SSMRP), this methodology will be developed for a specific nuclear power plant and used to perform probabilistic sensitivity studies to gain engineering insights into seismic safety requirements. The system model is composed of a series of functions representing the various stages in the seismic analysis process, i.e., seismic input, soil-structure interaction, major structure response, subsystem response, fragilities of structures, systems, and components, load combination, and the overall system analysis. Transfer functions are being developed to relate the input seismic environment and the output response for each design and analysis state, i.e., soil-structure interaction, major structure response, and subsystem response. Sensitivity studies are being performed to identify random variables and to characterize uncertainties.

In this paper, random variables in the structural response analysis area, or parameters which cause uncertainty in the response, are discussed and classified into three categories, i.e., material properties, structural dynamic characteristics and related modeling techniques, and analytical methods. The sensitivity studies are grouped into two categories, deterministic and probabilistic. Deterministic sensitivity studies are designed to establish the relative importance of parameters within each stage in terms of their contribution to the uncertainty of final response results. The probabilistic distribution parameters which have the most contribution are then input into the system model. A probabilistic sensitivity study is performed with the system model to establish the relative importance of parameters, or random variables, among the seismic analysis stages. In a system analysis, transfer functions in simple form are needed since there are too many responses which have to be calculated in a Monte Carlo simulation to use the usual straightforward calculation approach. Therefore, the development of these simple transfer functions is one of the important tasks in SSMRP. Simplified as well as classical transfer functions are discussed in this paper.

● **6.13-24** Cummings, G. E. and Wells, J. E., **Systems analysis methods used in the Seismic Safety Margins Research Program,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 3/2, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In order to provide insights into the seismic safety requirements for nuclear power plants, a probabilistic-based systems model and computational procedure have been developed. This model and computational procedure will be used to identify the areas where data and modeling uncertainties need to be decreased by studying the effect of these uncertainties on the probability of radioactive release and the probability of failure of various structures, systems, and components. From the estimates of failure and release probabilities and their uncertainties, the most sensitive steps in the seismic methodologies can be identified. In addition, the procedure will measure the uncertainty resulting from random occurrences, e.g., seismic event probabilities, material property variability, etc. Discussed are the elements of this systems model and computational procedure, the event-tree/fault-tree development, and the statistical techniques to be employed.

● **6.13-25** Contreras, H. and Scholl, R. E., **Stochastic finite element structural models,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. M, Paper M 10/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

In a new approach to account for the main sources of uncertainty in the analysis and design of structures, stochastic differential and difference equations are combined with the finite element method. Loads for multidimensional structures are idealized as stochastic processes and incorporated into finite element dynamic models with uncertainty in their parameters. The theoretical basis of the stochastic differential and difference equations and the finite element method are presented. Stochastic finite elements are introduced as a means to identify or consider uncertainty in parameters. Seismic disturbances are used as an illustration for simulating loads with stochastic processes. Numerical examples show the capabilities and feasibility of the proposed methodology.

● **6.13-26** Spanos, P.-T. D., **Equations for probabilistic earthquake energy spectra,** *EMRL 1131,* Engineering Mechanics Research Lab., Univ. of Texas, Austin, Oct. 1979, 25.

The response of a lightly damped linear structure to a broad-band nonstationary random process with evolutionary spectrum has been considered. A first-order stochastic differential equation governing the evolution in time of the energy of the linear structure has been derived. The associated Fokker-Planck equation has been used to obtain a first-order ordinary differential equation describing the time evolution of the mean energy of the structure. This equation admits a heuristic interpretation based on energy balance concepts. Its solution has been derived in a closed form. This form has been used to examine analytically some properties of the maximum mean energy of the structure which could be expected by arguing on an intuitive basis. Several models of nonstationary random processes used to simulate earthquakes have been examined. Equations have been given for the maximum value of the mean energy of the structure over the entire duration of the earthquake excitation. These equations are quite appropriate for readily conducted parametric studies of the effect on the structural response of the peak, duration, and frequency characteristics of the earthquake excitation. In addition, average response spectra can be readily constructed by utilizing an approximate relationship of the mean energy of the structure and the mean square value of the structural response to the earthquake excitation.

● **6.13-27** Spanos, P.-T. D., **Stochastic linearization method for dynamic systems with asymmetric nonlinearities,** *EMRL 1126,* Engineering Mechanics Research Lab., Univ. of Texas, Austin, Sept. 1978, 37.

A linearization scheme has been presented for multidegree-of-freedom dynamic systems with asymmetric nonlinearities subjected to Gaussian excitation. The asymmetry of the nonlinearity has been accounted for by including a deterministic offset component in the random system response. Explicit formulas for the construction of the equivalent linear system are given. This system is used to obtain nonlinear ordinary differential equations governing the time evolution of the response covariance matrix. The reliability of the proposed method has been examined in the context of a specific asymmetric dynamic system subjected to uniformly and exponentially modulated Gaussian white noise.

● **6.13-28** Der Kiureghian, A., **On response of structures to stationary excitation,** *UCB/EERC-79/32,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 42. (NTIS Accession No. PB 80 166 929)

Stationary responses of single- and multidegree-of-freedom structures subjected to stationary input excitations are studied. By means of a modal superposition procedure, closed-form solutions are derived for the first three spectral moments of response to white noise and filtered white noise inputs. These solutions account for the correlation between modal responses of multidegree structures; thus, they are applicable to structures with closely spaced modes. Special attention is given to excitations which are typical of earthquake ground motions. Various quantities of response can be obtained in terms of the three spectral moments. These include the mean squares of the response and its time derivative and, in the special case of Gaussian response, the mean zero-crossing rate and the mean, variance, and distribution of the peak response over a specified duration. In this regard, improved, semi-empirical relations for the mean and variance of the peak of a stationary Gaussian process are developed. Results from the study demonstrate the range of applicability of the white noise model as an approximation for wide-band inputs.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **6.13-29** Vanmarcke, E. H., **On the scale of fluctuation of random functions,** *Research Report R79-19,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Apr. 1979, 59.

New results are presented for the average crossing rate and for the probability distribution of extremes of moving averages or integrals of random processes that are ergodic in the mean. The results are asymptotically exact when the averaging time grows to infinity and provide excellent approximations for all but very small averaging times. The report provides new perspectives on the unifying role of the Gaussian random process toward which any stationary random process converges through "local" averaging or integration. The scale of fluctuation is identified as a key parameter of any stationary random process. It is formally defined in terms of the variance function, but it has simple interpretations in terms of the autocorrelation function and the spectral density function. It is shown how the scale of fluctuation can be derived for filtered random processes and for sums of random processes, and how it can be estimated from sample functions.

It is shown that results of the theory of interpolation and extrapolation of random functions can be simplified and made more practically useful by reinterpretation in terms of the scale of fluctuation. It is also shown that a broad class of wide-band stationary random processes may be represented by three parameters, with one parameter capturing information about correlation sufficient for many practical purposes. It is also shown how this type of stochastic modeling can be extended without sacrificing simplicity by considering sums of independent "three-parameter" processes.

6.13-30 Takaoka, N., Shiraki, W. and Yamane, K., **Reliability analysis of structural members composed of several random elements with theory of stochastic processes,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 8-9. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 269,* Jan. 1978, 29-39.)

In this paper, a reliability analysis of structural members is made considering both the load and the member resistance to be composed of several random elements (components). A general formula is deduced for evaluating the probability of failure of a structural member in which the resistance of the section is determined by the strengths of n constituent materials, when the structural member is acted on by a time-varying load which constitutes m random components. It is assumed that the random components of both the load and the member resistance have arbitrary probability distributions. The analysis is based on the theory of linear statistical approximation. The general formula mentioned above is applied to a special case in which the random components of constituent materials are assumed to be normal (Gaussian) variables and those of the load to be stationary normal processes. To illustrate the application of the present theory, numerical calculations are carried out on a singly reinforced concrete beam with rectangular cross section. Only the concrete strength and the yield strength of the steel are considered as random components of the constituent materials.

6.13-31 Koike, T., **Dynamic reliability analysis of deteriorating structures,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 98-101. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 280,* Dec. 1978, 1-11.)

A method for analyzing the reliability of deteriorating structures with an uncertain resistance is developed. When a structure sustains random external loads, it may be acceptable that any physical changes such as fatigue, corrosion, or an extended plastic region should be induced in the structure. To illustrate this method, random fatigue failure in the crack propagating region is adopted to discuss the reliability parameters physically and stochastically dependent on the loading history.

6.13-32 Komatsu, S. and Nakayama, T., **First-passage failure probabilities of structures with scattered material strength under nonstationary random excitation,** *Transactions of the Japan Society of Civil Engineers,* **10,** Nov. 1979, 69-72. (Abridged translation of paper published in Japanese in *Proceedings of the Japan Society of Civil Engineers, 278,* Oct. 1978, 25-38.)

In a previous work, the undesirable effects of the variability of material strength on the first-passage failure probability of a lightly damped structure subjected to a stationary Gaussian random excitation have been investigated. The present paper is an extension of the previous paper to the case where the random excitation is nonstationary.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

7. Earthquake-Resistant Design and Construction and Hazard Reduction

7.1 General

● 7.1-1 Yamada, M. and Kawamura, H., **Ultimate aseismic design of structures and ground motions for design-based upon the history of ultimate aseismic design** (in Japanese), *Transactions of the Architectural Institute of Japan*, 279, May 1979, 29-40.

The resonance fatigue method is the ultimate design method used in this paper. The method consists of polarization of the excitation and the response terms in the equation of motion. Input terms are such ground motion characteristics as acceleration, velocity, and displacement amplitudes, and the period and duration of an earthquake. Based on a simple fault model, quantitative estimates of ground motion characteristics are proposed as functions of epicentral distance, earthquake magnitude, and predominant period of the ground site.

● 7.1-2 Rosenblueth, E., **Optimum design to resist earthquakes**, *Journal of the Engineering Mechanics Division, ASCE*, **105**, *EM1*, Proc. Paper 14395, Feb. 1979, 159-176.

Optimization is defined in this paper as the minimization of the sum of the expected present values of initial costs (including engineering services and construction) and magnified losses resulting from the entrance of a structure into limit states. Dead, live, and seismic loads are considered. Attention is given to optimum repair and reconstruction policies; this problem is formally identical with optimization of resource allocation to research and development. Expenditures in engineering services are taken as a constant. Except for uncertainty about maximum possible seismic intensity, uncertainties call for approximately multiplicative safety factors. Under some conditions, design live loads under earthquakes exceed those under gravity alone.

● 7.1-3 Rosenblueth, E., **Optimum expenditures in seismic design**, *Journal of the Engineering Mechanics Division, ASCE*, **105**, *EM1*, Proc. Paper 14396, Feb. 1979, 177-187.

Optimization is defined as the minimization of the sum of the expected present values of initial costs (including engineering services and construction) and magnified losses resulting from the entrance of a structure into limit states. Dead, live, and seismic loads are considered. Attention is given to the optimization of expenditures in engineering services. The treatment is extended to consider optimization of resource allocation to research and development. Professional uncertainty and human errors depend on the investment in structural engineering services, which can be optimized. For N nominally identical structures, the optimum expenditures on analysis, design, and revision per unit grow approximately as $N^{1/2}$, while the optimum on supervision varies little with N. Under some conditions, the most profitable research effort at present consists in improving knowledge about seismicity.

● 7.1-4 Hatrick, A. V., **Seismic risk and design criteria**, *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering*, New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 149-163.

By making use of published data on the risks of earthquake occurrence in New Zealand and on the risks of structural failure in the event of an earthquake, a method is

● *See* ***Preface****, page v, for availability of publications marked with dot.*

developed for estimating the risks of structural failure resulting from earthquakes. These risks are compared with the provisions of the New Zealand national building code and with other risks which are accepted in daily life. The uses of these risks in economic decision-making is illustrated.

● **7.1-5** Oppenheim, I. J., **Economic analysis of earthquake engineering investment,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 467–476.

Two procedures for making investment decisions are reviewed in this paper. The procedures are considered to be basic operations in economic analysis. The first procedure is used to identify either an acceptable or an optimal investment for cases in which outcomes are known in advance. The second procedure is used for investments with probabilistic benefits.

Three hypothetical seismic design decisions are then analyzed. The two economic analysis procedures cannot reproduce any one of the three design decisions, implying that the decisions are inconsistent. The author introduces two additional analysis parameters—the influence of extreme risk and behavioral-organizational influences—which account for much of the gulf between observed patterns of practice and those which would be predicted by economic theory.

● **7.1-6** Green, N. B., **Earthquake resistant building design and construction,** Van Nostrand Reinhold Co., New York, 1978, 171.

This book presents a review of earthquake engineering as it concerns structures, and supplies pertinent general information concerning earthquakes. The latest earthquake-resistant design concepts are discussed, including ductility, damping, and the influence of energy absorption by structures. Areas of earthquake-resistant design not yet fully understood, such as the relation of static to dynamic forces, are discussed. The book is written from the standpoint of the practicing structural engineer, and effort has been made to explain practical methods of analysis and design that can readily be used in a design office. The book will also be of interest to the engineering student.

● **7.1-7** Martem'yanov, A. I., **A universal quantitative characteristic of building damage in earthquake resistance theory problems** (Universal'naya kolichestvennaya kharakteristika povrezhdennosti zdanii v zadachakh teorii seismostoikosti, in Russian), *Stroitel'naya mekhanika i raschet sooruzhenii, 1,* Feb. 1979, 40–45.

The need to make allowance for a quantitative measure of damage in problems involving optimization of economic risk and reliability of structures is proved. The measure of damage is expressed in terms of cost and changes in the period of natural vibration. A model for the evolution of natural vibrations of buildings throughout their useful life is discussed.

● **7.1-8** Breen, J. E. and Siess, C. P., **Progressive collapse—symposium summary,** *Journal of the American Concrete Institute,* 76, 9, Title No. 76-42, Sept. 1979, 997–1004.

This paper summarizes the major ideas presented at a two-day ACI Symposium on Progressive Collapse, held in conjunction with the ACI Annual Convention, Apr. 9, 1975, in Boston. The basic nature of the problem of progressive collapse is defined, the relationship of abnormal loading to discussions of progressive collapse is illustrated, and basic regulatory approaches are outlined. The area of progressive collapse is examined in relation to an overall safety philosophy. It is concluded that it is necessary to keep the level of risk of a progressive collapse lower than that of a local failure because of the effect of scale. The paper discusses future directions and states that, at the end of this symposium, the structural engineering profession in the U.S. was still undecided about whether specific regulations were required to minimize the risk of progressive collapse.

● **7.1-9** Jennings, P. C. and Housner, G. W., **The determination of earthquake design criteria,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 52, 40.

The earthquake-resistant design of structures is important in seismic regions from the point of view of safety and economical construction. The engineering profession has the responsibility of providing the needed protection. The prime consideration in achieving this protection is the determination of proper design criteria. Because of the uncertain timing, location, and intensity of future earthquake motions, consideration must be given to the desired structural performance in response to moderate motions having a relatively high probability of occurrence, as well as very strong ground motion with a relatively low likelihood of occurring in the lifetime of the project.

The responsibility of achieving a satisfactory earthquake-resistant design normally rests with the project engineer, who in general is not an expert in the earthquake field. The present paper is an effort to explain to the project engineer the problems involved in formulation of earthquake-resistant design criteria and to provide guidance to him in seeking a satisfactory solution to these problems.

● *See **Preface,** page v, for availability of publications marked with dot.*

The paper begins with an introduction dealing with the problems of design and the function of earthquake design criteria. This section is followed by a discussion of the use of seismological and geological data, with particular emphasis on the use of earthquake magnitude. The next section is devoted to the components of engineering criteria, including the design spectrum, the expected capacity of structures to resist strong ground motion, and modification of the design spectra to fit local conditions. Also included in this portion is a discussion of the role of statistical and probabilistic analyses. The final parts of the paper examine the margin of safety in earthquake-resistant design and pose some questions that can help the project engineer to achieve appropriate earthquake-resistant design criteria.

● **7.1-10** Mostaghel, N. and Ahmadi, G., **Smooth site dependent spectra,** *EEC 78.2, Report 4,* Earthquake Engineering Center, Pahlavi Univ., Shiraz, Iran, Oct. 1978, 103.

Based on the characteristic site period and the presumed peak ground acceleration, a method is proposed for the construction of smooth site-dependent spectra. Smooth spectra are plotted and compared with spectra of many actual records. To show the generality of the proposed method, the records used for comparison are selected to have small, intermediate, and relatively large predominant periods with various intensities from relatively small, intermediate to large events. The agreement in all cases is very good. The proposed site dependent spectra are also compared with Newmark's and the Regulatory Guide 1.60 spectra. The comparison is favorable for a limited range of characteristic site periods.

● **7.1-11** Gaylord, Jr., E. H. and Gaylord, C. N., **Structural engineering handbook,** 2nd ed., McGraw-Hill Book Co., New York, 1979, 1 vol.

This handbook contains the following sections: Section 1—Structural Analysis: Part 1. Elastic Systems by J. Graham and W. G. Godden; Part 2. The Finite-Element Method by W. C. Schnobrich and J. Graham; Section 2—Computer Applications in Structural Engineering by S. J. Fenves; Section 3—Earthquake-Resistant Design by N. M. Newmark and W. J. Hall; Section 4—Fatigue and Brittle Fracture by W. H. Munse; Section 5—Soil Mechanics and Foundations: Part 1. Soil Mechanics by H. G. Larew; Part 2. Soil Exploration by T. H. Thornburn; Part 3. Retaining Structures and Foundations by H. O. Ireland; Section 6—Design of Steel Structural Members by W. J. LeMessurier, H. W. Hagen and L. C. Lim; Section 7—Plastic Design of Steel Frames by L. S. Beedle and T. V. Galambos; Section 8—Fabrication and Erection of Structural Steel: Part 1. Fabrication by C. F. Harris; Part 2. Erection by D. B. Rees: Section 9—Design of Cold-Formed Steel Structural Members; Section 10—Design of Aluminum Structural Members by J. W. Clark; Section 11—Design of Reinforced Concrete Structural Members by R. C. Reese and P. M. Ferguson; Section 12—Design of Prestressed Concrete Structural Members by T. Y. Lin and P. Zia; Section 13—Concrete Construction Methods by F. A. Vitolo; Section 14—Composite Construction by W. H. Fleischer et al.; Section 15—Masonry Construction by W. L. Dickey; Section 16—Timber Structures by K. P. Milbradt; Section 17—Arches and Rigid Frames by T. C. Kavanagh and R. C. Y. Young; Section 18—Bridges: Part 1. Steel and Concrete Bridges by A. L. Elliott; Part 2. Steel-Plate-Deck Bridges by R. Wolchuk; Section 19—Buildings: Part 1. General Design Consideration by S. J. Y. Tang and S. G. Haider; Part 2. Industrial Buildings by E. A. Picardi; Part 3. Tall Buildings by M. H. Eligator and A. F. Nassetta; Section 20—Thin-Shell Concrete Structures by D. P. Billington; Section 21—Suspension Roofs by L. Zetlin and I. P. Lew; Section 22—Reinforced-Concrete Bunkers and Silos by G. Gurfinkel; Section 23—Steel Tanks By R. S. Wozniak; Section 24—Towers and Transmission Pole Structures by M. Zar and J. R. Arena; Section 25—Buried Conduits by R. J. Krizek; Section 26—Chimneys by M. Zar and S.-L. Chu. The handbook also includes a subject index and an appendix.

● **7.1-12** Mostaghel, N. and Ahmadi, G., **Smooth site dependent spectra,** *Nuclear Engineering and Design,* **53**, 2, July 1979, 263-300. (For an abstract and an additional reference, see Abstract No. 7.1-10.)

7.2 Building Codes

● **7.2-1** Mathieu, H., **Loadings-CEB approach,** *Concrete Design: U.S. and European Practices,* Paper No. SP 59-2, 23-34. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper summarizes an important chapter in the CEB (Comite Euro-International du Beton) Safety Manual published in 1975. The paper reviews general problems encountered with loads in the management of structural safety. Different qualitative classifications of load actions, idealizations, and representative values are discussed. Other problems such as combinations of actions and specific problems occurring during erection are treated in other chapters of the manual.

● **7.2-2** MacGregor, J. G., **Design of beams, deep beams, and corbels for shear-ACI 318-71 and revisions proposed by ACI Committee 426,** *Concrete Design: U.S. and European Practices,* Paper No. SP 59-5, 71-91. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper reviews the philosophy of the 1971 ACI (American Concrete Inst.) Building Code sections on shear and the revisions recently proposed by ACI Committee 426. The design of reinforced and prestressed beams for shear is discussed. In addition, the use of shear friction and the design of deep beams and corbels are examined.

● 7.2-3 Thurlimann, B., **Shear strength of reinforced and prestressed concrete-CEB approach,** *Concrete Design: U.S. and European Practices,* Paper No. SP 59-6, 93-115. (For a full bibliographic citation, see Abstract No. 1.2-7.)

In addition to a standard method derived from semi-empirical considerations, the new CEB (Comite Euro-International du Beton) model code proposes a refined method for the design of reinforced and prestressed concrete members subjected to bending and shear. The method is compatible with the design method for torsion and combined cases of bending, shear, and torsion. The method is theoretically based on the plastic analysis of a truss model consisting of two stringers acting as compression and tension chords, with stirrups as posts and a continuous concrete compression field acting at a variable inclination. The model is explained and the design formulas for the refined method are derived. Comparisons are made with appropriate test results as well as with the CEB standard method.

● 7.2-4 Macchi, G., **Limit states design for reinforced and prestressed concrete-CEB approach,** *Concrete Design: U.S. and European Practices,* Paper No. SP 59-4, 51-69. (For a full bibliographic citation, see Abstract No. 1.2-7.)

In this paper, the CEB (Comite Euro-International du Beton) concepts of limit states are illustrated. Safety formulation based on partial coefficients is explained, with particular reference to the problems of the nonlinear analysis of statically indeterminate structures and the uncertainty of the model. A ductility condition for linear analysis with redistribution is described, and the criteria for its derivation are outlined. The criteria for serviceability limit states are briefly summarized with reference to cracking and to deflections.

7.2-5 Nowak, A. S. and Lind, N. C., **Practical code calibration procedures,** *Canadian Journal of Civil Engineering,* **6**, *1*, Mar. 1979, 112-119.

This paper considers a procedure that can be used to determine safety indexes for structures and to calculate optimum performance factors for limit states design. Six load components are considered: dead, sustained live, transient live, snow, wind, and earthquake. The procedure is based on an approximation of the probability distributions by normal distributions in the design point situated on the failure boundary. The objective in selection of performance factors is closeness to a target safety level expressed in terms of the target safety index. A computer program was developed to be used in the calibration. The procedure is illustrated by examples.

● 7.2-6 Anderson, D. L., Nathan, N. D. and Cherry, S., **Correlation of static and dynamic earthquake analysis of the National Building Code of Canada 1977,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 653-661.

The intent of the Canadian National Building Code (NBC) (1977) is analyzed with respect to seismic force levels. The quasi-static force is correlated with ground acceleration levels. The level of risk actually associated with the NBC "major earthquake" is examined.

● 7.2-7 Heidebrecht, A. C., **Earthquake codes and design in Canada,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 575-608.

This paper discusses certain aspects of seismic codes and seismic design in order to clarify some of the issues and thereby assist the designer in applying seismic-resistant design principles. The paper discusses the purpose of seismic codes, with particular emphasis on codes applying to building structures. The objectives of the seismic loading provisions of the National Building Code of Canada (NBCC) are discussed in detail. The seismic design philosophy of the CANDU nuclear power plant is examined. A small study comparing wind and earthquake risk is described and concludes that the risks of failure are comparable. The relationship between response and excitation acceleration level for various ductilities and the role of serviceability in seismic design philosophy are examined. Detailed discussions of the roles of dynamic analysis and ductility in seismic design are then presented, based on the current provisions of the NBCC. The paper concludes with a short discussion of the development of the seismic loading provisions of NBCC, including both historical perspectives and current developments.

● 7.2-8 Newmark, N. M., **Earthquake resistant design and ATC provisions,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 609-651.

In general, the object of earthquake resistant-design is to enable a structure to resist, with little or no damage, the earthquake motions that might reasonably be expected to occur during the lifetime of a structure, thereby avoiding expensive repairs if a minor earthquake should occur. However, a more important purpose is to provide a large measure of resistance to, or to prevent, collapse or failure that might cause major property damage or loss of life in the event of a major earthquake, even if there is a rare probability of occurrence. Although, for the first case, a structure may be designed to remain elastic or nearly so, in the latter instance it is not reasonably economic to design for elastic behavior unless the structure is of such a character and of such importance that it might not be able

● *See **Preface**, page v, for availability of publications marked with dot.*

to fulfill its intended use, even with slight damage, after the earthquake.

The seismic design procedures discussed are restricted to buildings, although some aspects may be applied to other structures. The analytical methods described are of two types: (1) moderately rigorous procedures to determine the response of structures essentially in the elastic range, and (2) approximate procedures suitable for use in design. Only a brief summary is given of the more rigorous procedures, and attention is focused primarily on approximate procedures for design purposes. These procedures are embodied in the "Tentative Provisions for the Development of Seismic Regulations for Buildings," prepared by the Applied Technology Council. A brief summary of these provisions is contained in the paper.

● **7.2-9** Rowe, R. W., **General approach to safety, serviceability, and limit state philosophy-European Concrete Committee,** *Concrete Design: U.S. and European Practices,* Paper No. SP 59-1, 13-22. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper reviews recent developments in the field of structural safety and discusses the interpretation of these developments in codes of practice. Particular reference is made to the activities of the Joint Committee on Structural Safety, which is composed of members from the Comite Euro-International du Beton, the Convention Europeenne des Associations de la Construction Metallique, the International Council for Building Research, the Federation Internationale de la Precontrainte, and the International Assn. for Bridge and Structural Engineering.

● **7.2-10** Rosenblueth, E., **Seismic design requirements in a Mexican 1976 code,** *Earthquake Engineering & Structural Dynamics,* **7,** *1,* Jan.-Feb. 1979, 49-61.

The new version of Mexico's Federal District Building Code was officially approved in Dec. 1976. It differs from previous versions in several aspects: design values are based on a probabilistic assessment of seismicity, on a more careful and better substantiated consideration of wave filtering through the peculiar lacustrine soil, and on approximate design optimization; ductility receives explicit treatment; and there are significant improvements in the treatment of overturning moments, torques, etc. The paper discusses these matters and contains information on the evolution of the code in Mexico and on its implementation in the Federal District.

● **7.2-11** Ellingwood, B., **Reliability of current reinforced concrete designs,** *Journal of the Structural Division, ASCE,* **105,** *ST4,* Proc. Paper 14479, Apr. 1979, 699-712.

Recent trends in design standards development have encouraged the use of probabilistic limit states design concepts to simplify the design process and render it consistent for different materials and construction technologies. The development of such criteria requires that a large amount of data be gathered for perusal by standards writing organizations. These data should provide a measure of performance or reliability of existing designs so that the standards organizations will be apprised of the differences in construction technologies. This paper assesses reliabilities associated with existing reinforced concrete designs and provides a brief comparison with steel designs.

● **7.2-12** Ellingwood, B., **Reliability based criteria for reinforced concrete design,** *Journal of the Structural Division, ASCE,* **105,** *ST4,* Proc. Paper 14480, Apr. 1979, 713-727.

Probabilistic limit states design concepts have evolved over the past decade because of the potential that they afford for simplifying the design process and placing it on a consistent basis for various construction materials. Several criteria formats have been proposed; all have the common feature that their various load and resistance factors have a reliability basis. Two such criteria for reinforced concrete design are examined in this paper. The development of practical reliability-based design criteria is also illustrated. While these are consistent with appropriate measures of design uncertainty and reliability and have a well-established rationale, they retain the simple characteristics of existing criteria with which designers in the United States feel comfortable.

● **7.2-13** Upritchard, G. J., **The effect of earthquakes on services and equipment in buildings and a proposed code of practice,** *Engineering Design for Earthquake Environments,* Paper No. C179/78, 91-100. (For a full bibliographic citation, see Abstract No. 1.2-2.)

Building response to earthquakes and damage to building service systems are discussed. Upper level accelerations and seismic effects on service systems and equipment are examined. A seismic loading code for service systems is reviewed and suggestions are given for the design and specification of plant and equipment, including anchors for rigidly and for flexibly mounted items, systems which cross areas where breaks caused by seismic forces might occur, and elevator installations.

● **7.2-14** Cooney, R. C., **The structural performance of houses in earthquakes,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 325-351.

● *See **Preface,** page v, for availability of publications marked with dot.*

New Zealand light-timber-framed houses have not always performed satisfactorily, as damage reports from past earthquakes illustrate. Only four severe earthquakes have affected populated areas this century; therefore, house construction practices have tended to develop in response to gravity and wind loads. Such structures only inherently provide earthquake resistance. The recent publication of a new code of practice for such structures is partly intended to ensure adequate performance in a severe earthquake. This paper discusses the structural performance of houses in past earthquakes, the development of regulations governing the construction of houses, and the consequent developments in construction practices.

● 7.2-15 Upritchard, G. J., **The seismic restraint of building services—a code of practice,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 427–439.

The service systems of buildings subjected to earthquakes have suffered widespread and costly damage. Building codes are now incorporating provisions to reduce such damage. Some aspects of a proposed New Zealand code are reviewed.

● 7.2-16 Aoyama, H., **Recent trends in Japanese research and development for earthquake-resistant buildings,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 125–127.

● 7.2-17 McGavin, G. L., **An examination of aseismic legislation for nonstructural components in essential facilities,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 453–461.

This paper examines seismic building codes available to the author that deal directly with nonstructural components. Three major codes are considered in the text of this paper. Many of the codes reviewed as background material are virtual repeats of "parent codes" while others, such as the Applied Technology Council recommendations, take new steps to deal with nonstructural components in order to increase their chance for survival during and after a severe earthquake. Codes such as the "California Administrative Code–Elevator Safety Regulations" address the seismic environment in detail, but seriously restrict the functional aspects of essential facilities by requiring automatic elevator shutdown followed by detailed inspection sequences in the event of strong building motion. Seismic-resistant qualification procedures are available to the industry that would not require elevator shutdown except where hoistway collisions are imminent.

This examination of nonstructural earthquake legislation presents some of the various aspects of applicable codes, both positive and negative, that affect the functional capabilities of essential facilities. It also provides a basis for comparison and understanding of nonstructural component design and installation in essential facilities.

● 7.2-18 Warburton, R., **Recertification of private sector buildings: the Dade County experience,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 462–466.

One of the major problems in effectuating an earthquake hazards mitigation program is the lack of procedures for the continual routine monitoring of existing private sector construction to ensure maintenance of design quality over time. It has been recognized that significant buildings must be maintained at an appropriate level of quality to ensure minimal catastrophic losses. This recognition at the federal level, and at state and local levels in Florida is outlined in this paper together with material on the Dade County, Florida, recertification program which provides for periodic professional level inspection and certification of existing private sector buildings.

● 7.2-19 Tso, W. K. and Meng, V., **Torsional provisions in building codes,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 663–684.

The accuracy is discussed of the static code provision on torsional effect of the National Building Code of Canada, 1977 (NBC 77). A uniform frame-type monosymmetric 12-story building is used as an example. The static story torque is compared with the dynamic torque computed using the response spectrum technique as outlined in Commentary K of NBC 77. It is found that, for a building with uniform eccentricity, the static code torque estimate is good if the effect of consonant coupled torsional-lateral resonances is small. At consonant coupled resonance, the static code torsional provision underestimates the story torque by a factor of two. Also, it is shown that, for buildings with large eccentricity, consonant resonance is unlikely to occur and the current NBC requirement of doubling the computed torque for design is very conservative.

● 7.2-20 Vargas Neumann, J., **Considerations on diverse topics of seismic-resistant codes** (Consideraciones sobre topicos diversos de codigos sismo-resistentes, in Spanish), *Publicacion DI-79-01,* Dept. de Ingenieria, Pontificia Univ. Catolica del Peru, Lima, 1979, 44. (Presented at the Seminario Latinoamericano de Ingenieria Sismo-Resistente, held in Caracas, Jan. 1979.)

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● 7.2-21 Harris, J. R., Fenves, S. J. and Wright, R. N., **Analysis of tentative seismic design provisions for buildings**, *NBS Technical Note 1100*, U.S. National Bureau of Standards, Washington, D.C., July 1979, 595.

This report presents the results of a thorough study of the internal logic of the *Tentative Provisions for the Development of Seismic Regulations for Buildings* developed by the Applied Technology Council. The methods of analysis employed in the study provide objective measures of clarity, completeness, and consistency, and an alternative form in which to examine the technical validity of the provisions. These methods include decision logic tables for examining individual provisions, information networks for representing the precedence among provisions, and classification of the provisions to study their scope and arrangements. A formal representation of the provisions is presented by the data items, decision tables, networks, and classification systems developed in the study. An index and several alternate arrangements of the provisions are also included. Opportunities to improve the tentative provisions are identified and discussed, and considerations for their future development and implementation within various national standards are highlighted.

● 7.2-22 Ventura, C. E., **Recommendations for the elaboration of an antiseismic design code for Guatemala** (Recomendaciones para la elaboracion de un codigo de diseno antisismico para Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 53, 39.

This paper outlines some important aspects that should be taken into account in establishing a design and construction code for Guatemala. The main objective of such a code is the protection of human lives, property, and public welfare by regulating design and construction methods as well as the quality of materials and the use of the proposed structure.

● 7.2-23 Zsutty, T. C. and Shah, H. C., **Recommended seismic resistant design provisions for Algeria**, John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, June 1978, 51.

This report, the third for the project "Seismic Risk Analysis for Algeria," recommends seismic design regulations for buildings in Algeria. Included in the report are recommendations for the seismic zoning of the country and the corresponding lateral force design levels. Emphasis is given to the structural qualities of redundancy, plan symmetry, regularity, and construction inspection. Structures and structural members with good qualities should be designed for load levels similar to those of the 1973 Uniform Building Code whereas structures and members with poor qualities should be designed for load levels equal to or higher than those of the 1976 Uniform Building Code. Past earthquake experience has shown that the quality factor is far more important to damage reduction than are precise evaluations of ground motion input.

● 7.2-24 Colindres S., R., **Basis for the formulation of a seismic design code for El Salvador** (Bases para la formulacion de un reglamento de diseno sismico para El Salvador, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 60, 24.

● 7.2-25 Junfei, X., **Empirical criteria of sand liquefaction**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 10-22. (Bound separately as "Special Session on Earthquake Engineering in China [papers].")

Engineers in the People's Republic of China have paid much attention to the problem of sand liquefaction since the Niigata, Japan, and Alaska earthquakes of 1964 and the Xingtai, China, earthquake. Many post-earthquake field investigations and related soil explorations have been conducted. Some preliminary results obtained after the 1970 Tunghai earthquake became the basis for the sand liquefaction threshhold criteria in the Chinese seismic-resistant building code (TJ11-74). This paper explains the provisions related to liquefaction in the Chinese code and presents statistical results on liquefaction potential.

● 7.2-26 Pyle, D. T. et al., **Structural element index for building code requirements for reinforced concrete (ACI 318-77)**, *Concrete International*, 1, 12, Dec. 1979, 45-51.

An index is presented listing all the ACI Building Code section references for a number of common structural building elements. The index provides a reordering of the code requirements into a logical system from the point of view of the designer of a specific structural element.

● 7.2-27 Englekirk, R. E., **Development of a precast concrete ductile frame**, *Journal of the Prestressed Concrete Institute*, 24, 6, Nov.-Dec. 1979, 46-65.

Earthquake-resistant design techniques are dynamic. Code provisions and design procedures are changing as new data and comparative analytical data constantly are developed. The current Uniform Building Code has attempted to formulate the philosophy of ductile design in concrete. The complexities associated with ductile design have made many of the resulting code provisions quite conservative as they apply to cast-in-place reinforced concrete construction. When the UBC provisions are applied to prestressed concrete, they make the design of precast ductile frames a

● *See **Preface**, page v, for availability of publications marked with dot.*

virtual impossibility. If precast ductile frames are to become an economic feasibility two alternatives are available: (1) revise the Uniform Building Code design criteria to contain provisions which are based upon strain limits and ductility, allowing the design engineer more freedom in the development of the ductile frame; or (2) develop a set of code provisions that relate specifically to the design of precast ductile frames. The second alternative is the most appropriate at this time because defining acceptable limits for strain and ductility is currently not possible.

● 7.2-28 Rothwell, M. A., **Proposals for more realistic force levels for earthquake resistant design in the Caribbean and their effect on structural load bearing masonry particularly in Barbados**, *Proceedings of First Caribbean Conference on Earthquake Engineering*, 452-457. (For a full bibliographic citation, see Abstract No. 1.2-21.)

The current forces used by practising engineers in the Caribbean for earthquake design vary greatly, particularly with respect to load-bearing masonry, the most widely used vertical structural element. This paper surveys attempts, based on sometimes inaccurate and inadequate information, to impose a uniform code on engineers in countries as different in recorded risk as Barbados and Jamaica and makes new proposals for a practical and economical earthquake-resistant design approach for blockwork which would be appropriate for developing countries. The effect of the use of different levels of force on the design and cost of construction of load-bearing masonry is discussed.

● 7.2-29 Adams, A. D., **Current earthquake resistant structural design in Jamaica**, *Proceedings of First Caribbean Conference on Earthquake Engineering*, 419-451. (For a full bibliographic citation, see Abstract No. 1.2-21.)

● 7.2-30 Degenkolb, H. J., **Earthquake engineering—design philosophy and codes**, *Proceedings of First Caribbean Conference on Earthquake Engineering*, 495-541. (For a full bibliographic citation, see Abstract No. 1.2-21.)

● 7.2-31 Gupta, S. P., **Earthquake resistant design and construction code for buildings in India**, *Proceedings of First Caribbean Conference on Earthquake Engineering*, 542-553. (For a full bibliographic citation, see Abstract No. 1.2-21.)

The main provisions of the earthquake code provisions for building design in India are presented. Many changes which have been incorporated in the new code are pointed out and the philosophy for these changes is discussed. The code provisions of a few countries are compared to point out the similarities. The changes in the seismic zoning map of the country are elaborated. The urgency for writing specifications for the earthquake-resistant construction of small dwellings, which suffer maximum damage during earthquakes, is emphasized because at present no provision for this type of construction exists.

● 7.2-32 Chin, M. W., **Development of a revised seismic code for the West Indies**, *Proceedings of First Caribbean Conference on Earthquake Engineering*, 554-573. (For a full bibliographic citation, see Abstract No. 1.2-21.)

This paper briefly reviews the historical development of a draft code of practice for the earthquake-resistant design of structures in the West Indies and the need for an early revision of the code provisions is emphasized in light of the code's current inadequacies. Some of the important factors on which a consensus among practising engineers is required are discussed in relation to the basic objectives and desirable qualities of a workable West Indian seismic code. Included in the discussion is a brief review of some of the approaches used in the preparation of seismic risk zoning maps in the form of iso-acceleration contour maps and it is pointed out that such a map is an essential first step in hazard reduction and any seismic code revision. The need to allow for soil-structure interaction by means of an appropriate soil factor and spectral curves for different soil conditions is also emphasized. The paper concludes with an outline of a draft set of seismic provisions which is suggested as a basis for a revised seismic code for the West Indies.

● 7.2-33 Gensert, R. M., Chmn., ACI Committee 531, **Design and detailing of engineered masonry with the new ACI standard *Building Code Requirements for Concrete Masonry Structures***, American Concrete Inst., Detroit, 1979, 102. (Paper presented at ACI Seminar on the New *Building Code Requirements for Concrete Masonry Structures*, held in six regional locations, Sept.-Nov. 1979; sponsored by ACI Committee 531.)

● 7.2-34 **Uniform Building Code**, 1979 ed., International Conference of Building Officials, Whittier, California, 1979, 734.

● 7.2-35 **Uniform Building Code Standards**, 1979 ed., International Conference of Building Officials, Whittier, California, 1979, 1 vol.

This volume is a compact and concise presentation of all the national test, material, and special design standards referred to in the Uniform Building Code.

● 7.2-36 Prendergast, J. D. and Fisher, W. E., **Current and tentative seismic design provisions for buildings: preliminary comparisons**, *CERL-TR-M-270*, Construction Engineering Research Lab., U.S. Army Corps of Engineers, Champaign, Illinois, Aug. 1979, 52. (NTIS Accession No. AD AO75 204)

● *See **Preface**, page v, for availability of publications marked with dot.*

This report compares current and tentative seismic design provisions for two types of buildings: (1) Letterman Army Hospital, an existing 10-story, reinforced concrete building located in the Presidio of San Francisco, whose design was based upon the 1964 Uniform Building Code, and (2) a three-story, ductile moment-resistant steel frame building located in a region of high seismicity and designed as an essential building.

● 7.2-37 American Concrete Inst. Committee 531, **Building code requirements for concrete masonry structures (ACI 531-79) and commentary–ACI 531R-79,** *ACI Standard 531-79, ACI Report 531R-79,* American Concrete Inst., Detroit, 1979, 64.

ACI 531-79 covers the design of concrete masonry structures. It is written in such a form that it may be incorporated verbatim or by reference in a general building code. The quality and testing of materials used are covered by reference to the appropriate ASTM standard specifications. Among the subjects covered are permits and drawings; determination of masonry strength; inspection; mixing and placing of mortar and grout; laying of masonry units; control joints; wall bracing; embedded pipes and anchorage devices; reinforcement placement and anchorage; spacing, splicing, and development lengths for reinforcement; analysis and design; allowable stresses; deflection and shear; walls; columns; pilasters; composite construction; cavity walls; and special provisions for unusual loadings.

The commentary discusses some of the considerations of Committee 531 in developing the provisions contained in the code.

7.3 Design and Construction of Buildings

● 7.3-1 Derecho, A. T. and Iqbal, M., **Some problems related to the establishment of earthquake design force levels,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 685–718.

Selected problems associated with the determination of design force levels for use in earthquake-resistant design are presented. Design force levels considered are those pertaining particularly to isolated reinforced concrete structural walls. The approach adopted involves a correlation of results from comprehensive dynamic inelastic analyses and data from tests of large-size specimens subjected to slowly reversed loading.

Among the problems discussed are those relating to the determination of critical response values, with special reference to the choice of input motions. Also considered is the choice of an adequate measure of inelastic deformation from among several alternative measures proposed in the literature. The problem of correlating force demands obtained from dynamic inelastic analyses with capacity values determined from tests of large-size specimens subjected to slowly reversed loading is also discussed.

● 7.3-2 Grigoriu, M., **Risk dependent seismic design,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 465–492.

A simple method for seismic design is developed based on the mean failure rate or the mean crossing rate of the response vector out of the region of safe behavior for a structure. The components of the response vector are earthquake effects at the critical points of the structure. A knowledge of the spectral density of the ground acceleration, the target mean failure rate, and the modal parameters of the structure is needed for application of the method. Resultant structures are anticipated to fail at a mean rate smaller than the target value. Results reported for a shear frame and an asymmetrical structure demonstrate that the actual and the target mean failure rates are nearly equal for many situations of practical interest.

7.3-3 Bjorhovde, R. and Birkemoe, P. C., **Limit states design of HSS columns,** *Canadian Journal of Civil Engineering,* 6, 2, June 1979, 276–291.

Hollow structural sections (HSS) have come into increasing use for structural purposes over the past number of years. There are several reasons for this development, in particular, the advantages of such shapes from an architectural viewpoint, the strength inherent in a closed cross section, corrosion stability, and ease of maintenance. Because of their shape, the members are particularly suited for use as columns.

This paper presents a review of typical HSS production methods used throughout the world today, with emphasis on the effect of several important parameters that vary with the production process. Following a general discussion of column strength theory and its application to HSS columns, the paper evaluates the development of limit states design procedures for compression members. Special attention is paid to the requirements of the standard CSA S16.1-1974 and the studies that led to these rules. The philosophy of full-scale column testing and typical testing procedures are briefly outlined and detailed data are presented from experimental and theoretical studies on Canadian-produced HSS sections. Column tests conducted on heat-treated shapes are compared to other data from similar tests on columns produced by a variety of manufacturing processes. It was generally found that the heat-treated shapes performed better than the cold-formed column and that the cold-formed data varied considerably with manufacturer. Comparison with data from column

● *See **Preface**, page v, for availability of publications marked with dot.*

tests conducted in Japan and in Europe revealed that the Canadian shapes tended to fall within the upper portions of the data band. Preliminary recommendations for limit states design are presented to evaluate the strength of variously manufactured HSS members.

7.3-4 Degenkolb, H. J., **Practical design (aseismic) of steel structures,** *Canadian Journal of Civil Engineering,* **6,** 2, June 1979, 292-307.

Structural design to resist earthquakes is different from structural design for the more usual forces in that the loads are uncertain but much larger than the elastic resistance of the structure; consequently, the engineer must be concerned with cyclic postelastic performance of materials and systems, ductility, and the stability of structures near ultimate loads. Cyclical tests on members and connections for steel moment-resisting frames indicate very stable hysteresis in the plastic range, a very desirable characteristic. Moment-frame structures, however, are subject to large deflections with consequent damage to the point where secondary effects such as *P*-delta effects may become critical. Some observations indicate that better performance can be obtained by combining the ductile steel frame with concrete shear walls or with steel-braced frames. Tests in Japan and California suggest that large amounts of energy can be absorbed and large ductilities can be achieved by using eccentric connections with steel-braced frames.

7.3-5 Foschi, R. O., **A discussion on the application of the safety index concept to wood structures,** *Canadian Journal of Civil Engineering,* **6,** *1,* Mar. 1979, 51-58.

The special characteristics of wood as an engineering material, in particular high variability in strength and load-duration effects, are discussed from the point of view of limit states design formulations based on the safety index concept. It is concluded that wooden structures require different treatment than is used with less variable materials and that, because of load-duration effects, the safety index and the usual load-resistance formulation in limit states design become dependent on the load history.

● 7.3-6 Yamada, M. and Kawamura, H., **Resonance fatigue characteristics of structural materials and structural elements (Part V: ultimate aseismic structural design; fundamental concept and method)** (in Japanese), *Transactions of the Architectural Institute of Japan,* *277,* Mar. 1979, 13-22.

In this paper, a new fundamental concept of ultimate seismic-resistant design is introduced. Based on the resonance fatigue characteristics of structural materials and elements, the method was analyzed experimentally and analytically in Parts I-IV. Ultimate safety is quantitatively estimated by means of a direct comparison of the general resonance fatigue characteristics of structures in order that an index of deterministic or probabilistic values can be calculated. The purpose of the ultimate design is to make such index values maximum.

● 7.3-7 Igarashi, S. and Ogawa, K., **Studies on kinematic model of steel frames for aseismic design (Part 3: application of equivalent continuous system to aseismic design)** (in Japanese), *Transactions of the Architectural Institute of Japan,* *277,* Mar. 1979, 23-31.

In Part 2 an equivalent continuous system was proposed as a kinematic model for a framed structure; the system reasonably approximated such story stress responses as story shear and axial forces, overturning moments, and transverse forces on the beams. The present paper illustrates the application of story stress responses for earthquake-resistant design of steel framed structures and shows that the equivalent continuous system may be a useful kinematic model for design. An equivalent cross-sectional area is proposed as a measure representing the magnitude of those story stress responses which can be regarded as vectors with four components. The equivalent cross-sectional area was used to evaluate the maximum stress sustained in each member of the frame during earthquake excitations. A method to proportion members according to equivalent cross-sectional areas was devised to control the distribution of plastic deformations of members throughout the structure.

Two example frames were designed according to this method and seismic responses of the frames were investigated. Although the present method is still insufficient to produce uniform plastic deformations in structures, the results of the analysis indicate that overturning moments and transverse forces on beams are influencing factors which must be evaluated in the seismic response analysis. From this viewpoint, the equivalent continuous system, which represents the story stress responses in a multidimensional space, can be useful.

● 7.3-8 Paulay, T., **Capacity design of earthquake resisting ductile multistorey reinforced concrete frames,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 917-947.

A condensed step-by-step summary of the application of a recently developed capacity design method, as applied to earthquake-resisting ductile reinforced concrete frames in New Zealand, is presented. The theoretical inelastic dynamic response is discussed of three prototype frames, designed by the method and subjected to strong seismic excitations. The predicted maximum actions are compared with those used in the design. The design quantities, derived from a modified conventional elastic frame analysis for a code-specified lateral static loading, were found to ensure a very high degree of protection against hinging in

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

columns at and above the first floor. The method is also described as economical and practical. Areas in which improvements can be made in this deterministic design procedure are also outlined. The paper states that capacity design is very simple to apply and can ensure predictable behavior during severe random seismic excitations.

● **7.3-9** Humar, J. L., **Seismic design of buildings using a time-history method,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 745–777.

The feasibility of a proposed seismic design method for multistory frame buildings is discussed. The method employs a time-series elastic response analysis of the structure for a ground motion compatible with a design response spectrum. The correlation between the elastic and the elastoplastic response is investigated, and it is suggested that the design forces in the members of an elastoplastic structure can be obtained by applying appropriate reduction factors to the forces obtained in an elastic analysis.

An example is presented in which a multistory steel frame building with a large setback is designed for seismic forces by using the results of an elastic dynamic analysis for a selected ground motion and reducing the forces so obtained by applying one uniform force reduction factor to all girder moments and another smaller factor to all column moments and axial loads.

● **7.3-10** Zagajeski, S. W. and Bertero, V. V., **Selection of an optimum moment redistribution in seismic-resistant design of R/C ductile moment resisting frames,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1039–1062.

The results of a study oriented toward the selection of an optimum moment redistribution in seismic-resistant reinforced concrete frame structures are presented. The paper describes a computer-aided optimum inelastic design procedure developed by the authors for the design of reinforced concrete structures expected to experience a severe earthquake ground motion during their service lives. By modifying design constraints, the proposed design procedure can be used for different inelastic moment redistributions.

Three different inelastic designs of a ten-story, three-bay frame are presented. In addition, a design based on the results of elastic analysis and a design based on the negative moment redistribution allowed by ACI are discussed. In all designs, seismic design forces are found from an inelastic response spectrum.

A comparison of the five designs indicates that moment redistribution has only a minor effect on required material volume. However, redistribution can have a major effect on inelastic rotation demands in response to earthquake ground motions and can relieve steel congestion at beam-column joints by reducing negative design capacities. The proposed design procedure is shown to be a versatile tool for inelastic design. Various moment redistributions may be considered by imposing appropriate design constraints while at the same time satisfying serviceability criteria.

● **7.3-11** Mueller, P. and Becker, J. M., **Seismic characteristics of composite precast walls,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1169–1199.

This paper examines the role of vertical connections in the seismic response of composite walls used in large-panel precast concrete buildings. On the basis of this examination, a strong horizontal joint–weak vertical joint design philosophy is suggested. The shear medium theory, or continuous medium method, is briefly reviewed as it applies to the coupling phenomenon in precast walls. A simple explicit formula for the fundamental period of composite precast walls and coupled shear walls is presented.

Based upon the linear elastic characteristics, the effect is discussed of vertical connection stiffness, strength, and cyclic degradation on the inelastic seismic behavior of composite precast walls. Computer results are given which indicate that, if vertical connections can be developed that exhibit a stable elastoplastic hysteretic behavior, the walls and the vulnerable horizontal connections can be efficiently protected by deliberately designing weak vertical joints. With the actual behavior of presently used connections taken into account, the paper points out the need for the development of new vertical joints and mentions some promising approaches.

7.3-12 Anderson, D. and Islam, M. A., **Design of multistorey frames to sway deflection limitations,** *The Structural Engineer,* **57B**, *1*, Mar. 1979, 11–17.

A method is presented for the lowest-cost design of multistory rectangular steel frames with limited values of horizontal sway deflection. The frame is rendered statically determinate by assuming points of contraflexure. Realistic expressions for steelwork costs are obtained in terms of the moments of intertia of the members. These expressions are used, together with slope-deflection analysis, to derive equations for design. The equations are suitable for hand calculations, and the accuracy of the equations is found to be good by comparison with computer analysis. Account can be taken of restrictions on section size and change of

● *See **Preface**, page v, for availability of publications marked with dot.*

section, and of the lack of a *continuous* range of rolled sections.

● 7.3-13 Troy, R. G. and Richard, R. M., **Steel plate shear walls resist lateral load, cut costs,** *Civil Engineering, ASCE,* 49, 2, Feb. 1979, 53-55.

In this article, two new buildings are discussed in which a seldom-used stiffening system was used: steel plate shear walls. Reasons for using this system, rather than reinforced concrete shear walls or steel or concrete rigid frames, include cutting down on wall thickness, preventing concrete construction from pacing steel erection, avoiding complex concrete reinforcement, and reducing the amount of steel needed by up to one-half. In one case, the plate walls saved about $2.85 million over the cost of a moment-resistant frame; in the other building, $3.5 million was saved.

7.3-14 Ritchie, J. K. and Chien, E. Y. L., **Innovative designs in structural systems for buildings,** *Canadian Journal of Civil Engineering,* 6, *1,* Mar. 1979, 139-167.

Numerous innovations in the use of structural steel alone or in combination with other structural components have been tried and proven in North America during the past two decades. In numerous other fields of endeavor, mass production allows refinement in both function and cost. However, the "one-off" approach inherent in architectural and structural design of buildings in North America and the broad spectrum of projects (and clients) processed by any single consultant, in spite of any desired level of specialization, allow development of only the low end of the learning curve related to the use of a particular system.

This paper has two objectives: the first is to review some of the innovative structural framing systems for steel buildings, presenting the concepts and design details for review by others who only infrequently have opportunities to design a structure falling in one of these categories; the second is to review possible adaptations of these structural systems with the objective of achieving greater construction efficiency, greater economy, or both. Systems reviewed include concrete-cored, gravity steel-framed structures with a number of alternative construction methods, staggered truss-framing systems, interstitially framed hospital structures and mechanical-structural interface aspects, the stub-girder framing system with Canadian alternatives, steel-concrete composite action of vertical and horizontal structural members, efficient lateral load-resisting systems such as direct-acting tension and compression bracing, including exterior and interior applications, steel-plate shear walls as lateral load-resisting elements, and combinations of the above. Structural interface with other building components including wall components receives considerable emphasis, but the primary focus is on ways and means of improving productivity in design and construction.

● 7.3-15 Raper, A. F. and Buchanan, B. W., **Evaluation of reinforcing bar mechanical splicing systems and recommendations for seismic design,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 741-759.

Five-bar splice systems were tested (in air) for strength and rigidity under cyclic loads from tensile to compressive yield; the cyclic loads simulated earthquake loading. In this paper, criteria for three grades of splices are established, according to performance, and design and detailing recommendations are made. All the swaged systems tested performed as effectively as continuous bar systems. A metal-filled sleeve splice exhibited slippage but performed relatively well under repeated loads; however, analytical analyses of column sections incorporating slipping splices suggests poor performance when the column carries a significant axial load.

● 7.3-16 Zagajeski, S. W. and Bertero, V. V., **Optimum seismic-resistant design of R/C frames,** *Journal of the Structural Division, ASCE,* **105**, *ST5,* Proc. Paper 14583, May 1979, 829-845.

A procedure for the optimum seismic-resistant design of reinforced concrete frames is presented. Based on a computer-aided iterative technique, the procedure consists of two main phases: (1) a preliminary design phase, which is repeated until an acceptable preliminary design is obtained; and (2) a final design phase. Seismic design forces are found from an inelastic design spectrum employing a modal analysis technique. A weak-girder, strong-column design criterion is imposed and member design is based on a story-wise optimization procedure using a linear programming technique. Once a design is obtained, a series of linear and nonlinear structural analyses are carried out in the preliminary design phase to evaluate the acceptability of the design and in the final design phase to evaluate the reliability of the design. Two designs obtained by employing the optimization procedure and a design based on UBC seismic forces and conforming to the requirements of this code are compared with respect to the volume of material required and the response characteristics. The use of computers allows alternate designs to be rapidly and economically formulated and evaluated.

● 7.3-17 Jagadish, K. S., Prasad, B. K. R. and Rao, P. V., **The inelastic vibration absorber subjected to earthquake ground motions,** *Earthquake Engineering & Structural Dynamics,* 7, *4,* July-Aug. 1979, 317-326.

Two-story bilinear hysteretic structures are studied to explore the possibility of using the dynamic vibration absorber concept in earthquake-resistant design. The response of the lower story is optimized for the Taft 1952, S69°E accelerogram with reference to such parameters as

● *See* ***Preface****, page v, for availability of publications marked with dot.*

the frequency, yield strength, and mass ratios. The influence of viscous damping is also examined.

● 7.3-18 Derham, C. J., Thomas, A. G. and Kelly, J. M., **A rubber bearing system for seismic protection of structures,** *Engineering Design for Earthquake Environments,* Paper No. C175/78, 53–58. (For a full bibliographic citation, see Abstract No. 1.2-2.)

For over ten years rubber and steel laminated bearings have been used increasingly for vibration isolation of entire buildings on problem sites near surface or underground traffic. A modification of this construction technique has been examined which can provide protection from earthquakes. It is shown that, in suitable areas, the system is capable of reducing earthquake shock forces in the structure to easily manageable levels at which both the structure and its contents can be protected. Mathematical modeling of the behavior of the structure on its rubber bearings has shown excellent agreement with experimental results and should be suitable for design studies.

● 7.3-19 Zimmerli, B. and Thurlimann, B., **Strength interaction surfaces for tall buildings,** *Journal of the Structural Division,* ASCE, **105,** ST3, Proc. Paper 14426, Mar. 1979, 481–492.

A common reference system is presented for the load surface and the strength surface of a tall building subjected to vertical and lateral loads. As an example, the different shapes of the strength surface are given for a simple space truss. In the preliminary design, the strength surface enables the engineer to select a system, which meets the requirements of the predicted load surface, by selecting the appropriate system parameters. In the final design, the comparison of the load and strength surface provides the safety margins for all load combinations in any direction.

● 7.3-20 Blakeley, R. W. G. et al., **Recommendations for the design and construction of base isolated structures,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 185–226.

The philosophy of base isolation of structures, generally using flexible mountings and mechanical energy-dissipating devices, is reviewed. Applications of the approach to buildings, bridges, nuclear power plants, equipment, and structures rocking on their foundations are described. Where possible, recommended code provisions and design rules are given. The characteristics of the mechanical energy-dissipating devices developed to date are discussed and material specification provisions presented. The requirements for construction of base-isolated structures and for maintenance of the devices are given. Recommendations are made regarding areas needing further research.

● 7.3-21 Megget, L. M., **Analysis and design of a base-isolated reinforced concrete frame building,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 227–236.

This paper describes the dynamic and static analyses and design of a four-story, ductile, reinforced concrete frame structure isolated from the foundations by elastomeric bearings incorporating lead energy dampers. Results from inelastic, time-history analyses for the isolated and nonisolated structure are compared for several input earthquake motions. The benefits of energy dampers in reducing the response of the isolated building (shears, plastic hinge demands, and interstory drifts) are detailed. Differences from conventional ductile design and detailing as well as design recommendations are included.

● 7.3-22 Matthewson, C. D. and Davey, R. A., **Design of an earthquake resisting building using precast concrete cross-braced panels and incorporating energy-absorbing devices,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 237–248.

The design and the analysis of an irregular six-story office building are described. The building has an unconventional earthquake resisting system: a precast concrete cross-braced perimeter frame incorporating force-limiting devices (termed "inserts") in the form of enclosed axially yielding short steel members. A series of inelastic dynamic analyses indicates that the system very effectively combines the inherent strength and stiffness of the cross-braced frame with the energy-dissipating function of the yielding inserts. Initial cost estimates indicate that the construction of the building will prove to be particularly economic.

● 7.3-23 Sharpe, R. D., Binney, J. R. and McNaughton, D. J., **The development of the design of the ANZ head office building, Lambton Quay, Wellington,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 353–368.

The irregular shape of the site on which the multistory ANZ head office building is to be located has given rise to an interesting architectural solution, which in turn has required complex methods of analysis and design. This paper describes the development of the structural solution and the procedures set up to handle the design. Special mention is made of some of the difficulties encountered in following codified analysis methods.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 7.3-24 Nicoletti, J. P. et al., **Computer-aided structural analysis and design of the 37-storey Los Angeles Bonaventure Hotel,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 369–388.

This paper briefly describes and summarizes the computer-aided analyses and design of a complex convention hotel in Los Angeles. Static and dynamic seismic analyses were used for sizing the structural steel elements. The dynamic analyses were carried out for two postulated levels of seismic ground motion; these analyses included both response-spectrum and time-history methods.

● 7.3-25 Mitchell, T. N., **Seismic design of timber structures,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 716–740.

The seismic performance of wood structures is discussed in relation to the mechanical properties of wood and wood fasteners. The derivation of basic working stresses and working loads are outlined, and the load-deformation characteristics of wood and wood fasteners subjected to monotonic and cyclic loading are presented. The requirements of the existing and proposed codes are listed and design methods for structural elements to resist seismic loads presented. Connections for wood elements that provide stable, high energy–absorbing, ductile load-limiting behaviors are also discussed.

● 7.3-26 Paulay, T., **Developments in the design of ductile reinforced concrete frames,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 605–624.

A step-by-step summary of the application of a recently published capacity design philosophy applied to earthquake-resistant ductile reinforced concrete frames is presented. The theoretical inelastic dynamic response of three prototype frames designed by the method and subjected to severe seismic excitations is then reported. The predicted maximum actions are compared with those used in the design. The design quantities, derived from a modified conventional elastic frame analysis for a code-specified lateral static loading, are found to ensure a very high degree of protection against hinging in columns at and above the first floor. The method is said to be economical and practical.

● 7.3-27 Skinner, R. I. et al., **Hysteretic dampers for the protection of structures from earthquakes,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 643–664.

The development of hysteretic dampers for the protection of structures against earthquakes is described. Details of steel and lead devices and their application to bridges and base-isolated buildings are given. Steel devices are designed to absorb energy by plastic deformation in torsion or bending, while lead devices rely on plastic extrusion or shear. The characteristics of PTFE sliding bearings are also described; the possibility is discussed of using this type of bearing to permit sliding on base-isolated systems and to allow dissipation of energy in joints in conventional structures. The most promising development is in the lead rubber bearing which combines in one unit the properties of load-bearing and damping.

● 7.3-28 Buchanan, A. H., **Diagonal beam reinforcing for ductile frames,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 249–267.

This paper describes a system of diagonal beam reinforcing for reinforced concrete ductile frame buildings in seismic areas. The development and application of the system is described with reference to the design of an 18-story building. The proposed reinforcing system has a number of major structural advantages over conventional reinforcing. Moments and shears within the beam span can be resisted entirely by the main reinforcing. Plastic hinge lengths are substantially increased, and the hinging is kept away from the column face, allowing concrete strut action to be effective in resisting forces within the elastic beam-column joint.

● 7.3-29 Newmark, N. M. and Riddell, R., **A statistical study of inelastic response spectra,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 495–504.

The dynamic response of nonlinear systems subjected to earthquake excitations is considered in order to assess the reliability of currently used procedures for specifying inelastic design spectra. Special attention is devoted to the influence of structural damping combined with various types of material nonlinearity on the response of single degree-of-freedom systems. The resulting responses are studied statistically to derive amplification factors and improved rules for accurately determining inelastic design spectra for a range of conditions. The new rules differ somewhat from those now in use and take into account the effect of damping and aspects of stiffness degradation and bilinear resistance not previously considered in detail.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

● 7.3-30 Tezcan, S. S. and Civi, A., **Reduction in earthquake response of structures by means of vibration isolators**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 433–442.

● 7.3-31 Clark, W. D. and Glogau, O. A., **Suspended ceilings: the seismic hazard and damage problem and some practical solutions**, *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering*, New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 665–684.

Traditional ceilings in rigid buildings generally caused few problems during earthquakes. The introduction of modern suspended ceilings with light metal grids and lay-in tiles or light fittings has created an entirely new situation. The increased flexibility of modern buildings has added to the problem, particularly with respect to the integration of ceilings and partitions. The seriousness of the hazard was brought to the attention of New Zealand engineers in 1966, when, as a result of the Gisborne earthquake, a heavy tile ceiling in a bank building fell some 8 m. As a result, ceilings in new government-financed buildings in New Zealand were required to incorporate seismic-resistant detailing. Evidence from other earthquakes occurring in New Zealand and other countries, particularly San Fernando, 1971, and Managua, 1972, led in 1976 to the introduction of specific loading requirements in the New Zealand Code NZS 4203.

The introduction of a wide variety of ceiling and partition systems has increased the complexity of the problem and, consequently, the need for professionally engineered solutions. The paper discusses the theoretical considerations of the problem and relates these considerations to actual earthquake damage. Code requirements are reviewed, and a number of typical solutions are presented. Economics are briefly discussed, and, in conclusion, the authors refer to a number of aspects not fully understood at present. Suggestions are made for further study and testing to clarify dynamic aspects and fire barrier problems.

● 7.3-32 Casciati, F., Faravelli, L. and Gobetti, A., **Reliability of seismic-resistant frames designed by inelastic spectra**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 553–562.

This paper investigates the reliability level of structures designed by using inelastic spectra at different values of the load factor. The limit state considered is defined by excessive inelastic deformation. This study is performed with reference to a specified multistory frame in a given seismic region. Random variables are used to describe the variability in time of the ground acceleration. The reliability of the frame is evaluated by assuming an extreme distribution for the structural inelastic response. The parameters of this distribution function are calculated by means of a simulation procedure. For this purpose, the structural response to each artificial accelerogram is determined via a step-by-step integration technique on a simplified model of the actual frame.

The structure designed by using the elastic response spectrum is first considered. Its reliability is then assumed as the required safety level in order to estimate the more suitable value of the load factor to be employed when inelastic spectra are used in seismic-resistant design. Finally, some extensions to geometrically nonlinear behavior are developed.

● 7.3-33 Eagling, D. G., **Earthquake safety at the Lawrence Berkeley Laboratory**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 82–89.

● 7.3-34 McKevitt, W. E. et al., **Towards a simple energy method for seismic design of structures**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 383–392.

The yield strength ratio (YSR) is suggested as a method for specifying the design lateral force level for a structure. Strong parallels exist between the YSR and the procedure embodied in current North American practice. The classification of structures by means of the YSR is closely analogous to the classification by means of the K-factors in the Canadian and American codes. It is felt, however, that the present method gives more explicit attention to the manner in which structures respond to earthquakes. The method easily lends itself to a type of limit states design in which the required energy capacity, and hence the deflections and damage levels associated with different levels of seismic activity, can be computed. Because the method accounts for the way in which energy is absorbed throughout a structure, it is anticipated that concentrations of damage, such as occurred in the ground floor of the Olive View Hospital during the 1971 San Fernando earthquake, would be revealed in advance. The method also facilitates the design of a system if viscous damping is to be deliberately built into a structure.

● 7.3-35 Fintel, M. and Ghosh, S. K., **Explicit inelastic dynamic analysis and proportioning of earthquake-resistant reinforced concrete buildings**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 393–402.

● *See **Preface**, page v, for availability of publications marked with dot.*

This paper proposes an alternative seismic design approach that represents a significant departure from the empirical code approach. The suggested procedure uses earthquake accelerograms as loading, dynamic inelastic response history analysis to determine member forces and deformations, and resistances determined from tests for proportioning the members.

● 7.3-36 Kustu, O., **A practical approach to damage mitigation in existing structures exposed to earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 487–494.

In this paper, a method of comparing structural strengthening schemes for existing buildings is presented. The method is intended to be used by owners or managers of existing buildings as a decision-making tool in the selection of the most economically feasible structural strengthening scheme in order to minimize expected financial losses from future earthquakes.

● 7.3-37 Tandowsky, S., **Seismic study of the George R. Moscone (Yerba Buena) Convention Center, San Francisco, California,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1046–1055.

The George R. Moscone Convention Center (formerly the Yerba Buena Convention Center) is to be a large, primarily underground structure located in the area south of Market Street in San Francisco. The building will be approximately 570 ft by 870 ft in plan dimensions and approximately 40 ft in height. It will be embedded into the ground approximately 30 ft. A consulting engineering firm was retained by the City of San Francisco in 1978 to: (1) develop seismic design criteria for use by the project designers; (2) develop design and detailing guidelines with special attention given to the critical elements of the structure; and (3) perform an independent, continuous review, concurrent with the design, to assure adherence to the criteria and guidelines and to allow identification and resolution of any potential problems at an early stage, thus avoiding potential costly delays. This paper describes the development of the seismic criteria and two special studies undertaken by the consulting engineers for the project.

● 7.3-38 Willsea, F., **Reconstruction of Margaret Jacks Hall, Stanford University,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1056–1065.

● 7.3-39 Muto, K., Sugano, T. and Inoue, N., **Study on aseismic capacity of a HiRC (highrise reinforced concrete) building referenced to newly proposed codes in Japan and U.S.A.,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 959–968.

Considering the design codes currently proposed in Japan and the United States, this paper re-evaluates the seismic-resistant capacity of a 25-story apartment building composed of reinforced concrete frames that are moment-resisting. A dynamic design procedure given special approval by the Japan Ministry of Construction is used to confirm the capacity of the building. It is found that the building has 1.1 times the capacity required by the proposed Japanese new building standard and twice that required by the Applied Technology Council's ATC-3 provisions.

● 7.3-40 Kulka, F., Teran, J. F. and Tai, J., **Rehabilitation of buildings damaged by earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 943–952.

● 7.3-41 Holmes, W. T., **The rehabilitation of History Corner of the Stanford University Main Quad,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 933–942.

● 7.3-42 Englekirk, R. E., **Component analysis—will it lead to safer, more economical structures?,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 913–922.

Current code force levels seem to be appropriate for the design of concrete shear walls. The application of these force levels to components causes inconsistent factors of safety and a general overconservatism. A consistent design approach is not possible with the analytical models currently used for lowrise structures. A consistent analytical approach can be obtained only with the use of models that consider the dynamic characteristics of the components. The majority of structures are of the lowrise type, and the development of safe, economical designs for this class of structures should be of high priority. Because component analysis seems to be more consistent with the observed behavior of structures and analytical concepts, it should be incorporated into building codes as rapidly as possible. Component analysis must permit safer and more economical lowrise structures.

● 7.3-43 Razani, R., **Criteria for seismic design of low-rise brittle buildings in developing countries,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 813–822.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Lowrise buildings with brittle lateral load-resisting systems, such as unreinforced masonry and low-cost adobe housing, constitute more than 90% of the buildings in urban and rural areas of the less-developed countries. The level of earthquake protection required in a country is in proportion to the level of development of that country. A suitable earthquake protection policy for lowrise, low-cost housing of a brittle type in seismically active less-developed countries is described. According to this policy, no property damage should occur during low- or moderate-intensity earthquakes and no death-causing roof collapses should occur during high-intensity moderate or major earthquakes. This policy gives priority to designs of collapse-resistant buildings and discourages heavy investment in the design of buildings resistant to all types of damage. Property damage may be compensated for by a system of national earthquake damage insurance. On the basis of the proposed policy, suitable criteria for the protection of buildings against earthquake damage and collapse in terms of maximum safe earthquake intensities are developed. A simple quantitative relationship between earthquake intensity and peak ground acceleration is obtained, and, for each level of earthquake intensity, a ground motion spectrum is proposed and a corresponding structual response spectrum is determined. Simple design spectra are suggested for various classes of lowrise brittle buildings, such as unreinforced masonry and low-cost adobe housing, and minimum required design lateral loads and base-shear coefficients for protection against earthquake damage and collapse are obtained.

● **7.3-44** Benedetti, D. and Castellani, A., **Comparative tests on strenthened stone-masonry buildings,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 793–802.

Rural and urban settlements in the seismically active areas of Europe consist primarily of old masonry structures constructed with no provision for horizontal forces. To reduce the vulnerability of such structures to earthquakes, strengthening can be employed. This paper provides an experimentally obtained measure to evaluate the efficiency of several widely used strengthening techniques. One technique—slab substitution—costs approximately $10 per sq ft, a figure based on the authors' observations of reconstruction after the Friuli earthquakes of 1976.

● **7.3-45** Ikonomou, A. S., **The Alexisismon: an application to a building structure,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 443–452.

This paper describes a method for reducing seismic forces in structures by using elastic rubber and pot bearings as structural supports and vertical bars as breakable connecting elements. When a three-story structure was supported by the method, time-history analyses showed that the horizontal seismic forces and the resulting overturning moments were 10 to 20 times smaller than when the structure was supported in the classical manner. With use of the method, structural and nonstructural members remain in the elastic stress range, regardless of earthquake intensity.

● **7.3-46** Gabrielsen, B. L. and Lindskog, R., **The use of structural foams to improve earthquake resistance of buildings,** Scientific Service, Inc., Redwood City, California, June 1978, 310. (NTIS Accession No. PB 287 121)

This report presents the results of a research program to investigate the use of foams to improve the earthquake resistance of buildings. The objective of this program was to develop and test the feasibility of using polyurethane foam to increase the shear capacity of timber stud walls, timber joist floors, and ceilings and foundation-to-floor connections. The specific tasks were to develop foam placement techniques, to document increases in strength caused by foam, and to determine the feasibility of using these techinques in new construction. The results of this largely experimental program indicated that substantial increases in shear strength were achieved in walls, floors, and ceiling systems. For example, a typical sheathed roof or floor system designed according to current codes would have no seismic shear resistance. It was shown experimentally, however, that a floor system (2 in. x 8 in. joist, 1 in. x 8 in. sheathing) when enhanced with foam developed a 1650 lb-ft shear enhancement and a 2450 lb-ft composite shear capacity. The energy absorbed by a panel with foam was approximately 10 times that of a panel without. Tests of floor-to-foundation connections upgraded by foam also indicate substantial increases.

● **7.3-47** Montgomery, C. J. and Hall, W. J., **Seismic design of low-rise steel buildings,** *Journal of the Structural Division, ASCE,* **105,** *ST10,* Proc. Paper 14919, Oct. 1979, 1917-1933.

The behavior of selected lowrise steel buildings subjected to earthquake base motions is studied, and recommended techniques for the earthquake-resistant design of lowrise buildings are presented. The seismic response of buildings of practical proportions when subjected to seismic excitation is determined using inelastic time-history analysis. Practical methods of analysis, specifically the modal method and the quasi-static building code (equivalent lateral force) approach, are evaluated for use in estimating seismic response. For practical design purposes, it is suggested that the quasi-static approach for calculating shear distribution, overturning moments, and displacements

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

be employed. Practical guidelines leading to building design that can resist earthquake base motion with an adequate margin of reserve strength are presented. The study demonstrates that it is possible and desirable to employ modern principles of earthquake engineering for lowrise buildings with simple framing systems.

● 7.3-48 Goli, H. B. and Gesund, H., **Linearity in limit design of orthotropic slabs,** *Journal of the Structural Division, ASCE,* **105**, *ST10,* Proc. Paper 14928, Oct. 1979, 1901–1915.

Limit design of orthotropically reinforced concrete slabs can be carried out by means of the yield-line theory. In general, the method is quite cumbersome. It can be simplified by taking advantage of a linear relationship between the total yield moment capacity of the slab and its collapse load. This linearity is demonstrated for slabs with unsymmetrical boundary conditions. It is shown that changes in geometry, boundary conditions, and coefficient of orthotropy will only change the slope of the graph, not its linear character, and that changes in the ratios of positive to negative reinforcement have little or no effect on the collapse load.

● 7.3-49 Freeman, S. A., **Seismic design criteria for multistory precast prestressed buildings,** *Journal of the Prestressed Concrete Institute,* **24**, *3,* May–June 1979, 62–88.

The seismic design provisions of the Uniform Building Code are applied to a hypothetical 15-story precast prestressed office building located in a highly seismic area.

● 7.3-50 Koncz, T., **Assembly line speeds panel construction for low cost housing,** *Journal of the Prestressed Concrete Institute,* 24, 2, Mar.–Apr. 1979, 38–51.

An assembly line production technique, developed by the author, and used to construct 1000 low-cost precast concrete housing units for a housing project in Ain M'Lila, Algeria, is described. The system allowed employment of unskilled labor for most positions, while keeping panel production high enough to complete three apartments per day.

● 7.3-51 Biggs, J. M., Lau, W. K. and Persinko, D., **Aseismic design procedures for reinforced concrete frames,** *R79-21, Seismic Behavior and Design of Buildings Report 1,* Constructed Facilities Div., Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, July 1979, 79.

Twelve reinforced concrete frames are designed for earthquake and gravity loads using three different procedures for determining the seismic design loads. The three procedures are (1) The Uniform Building Code (UBC) static load approach, (2) modal analysis using inelastic response spectra, and (3) the substitute structure method. The frames are of 4, 8, and 10 stories. The validity of each design procedure is evaluated by a time-history analysis of each frame to determine maximum local ductility demands from both real and artificial ground motions. Results are presented in the form of maximum ductility demands in each story and floor of the frames.

None of the three methods is found to be completely satisfactory because the ductility demands, or amount of computed yielding, are not the same as intended in the design and are not evenly distributed over the frame. Furthermore, the 8- and 10-story frames designed by all three methods yield excessively in the upper stories because of the whiplash effect. However, the computed ductility demands are in no case large enough to indicate structural collapse; in this sense, all three methods produce satisfactory designs. Although the inelastic response spectrum approach produces slightly better results, the two more sophisticated methods do not produce significantly better designs than the simpler UBC approach.

● 7.3-52 Takahashi, S. K. and Lew, T. K., **Computer screening of real property inventory for seismic investigation modernization projects at naval installations,** *Technical Memorandum TM M51-78-21,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Sept. 1978, 36.

A U.S. naval regulation requires that structures being considered for modernization funding be evaluated for seismic adequacy to assure that they are reasonably safe from predicted earthquake forces. In compliance with this instruction, the Public Works Center, Naval Station, San Diego (NAVSTA) requested the Civil Engineering Lab. to provide guidelines for assessing the seismic adequacy of typical naval buildings considered for remodeling projects. These guidelines are intended solely to determine whether a seismic safety evaluation is necessary before initiating a modernization project. The seismic adequacy of critical buildings in modernization projects should be determined by the rapid analysis procedure which usually imposes a higher acceleration on the buildings than that procedure used to establish the guidelines.

This report lists buildings and utilities that require seismic investigation to precede modernization projects for the nineteen activities at NAVSTA, San Diego.

● 7.3-53 Chelapati, C. V., Takahashi, S. K. and Lew, T. K., **Earthquake hazard reduction program, North Island Naval Air Station, San Diego, CA,** *Technical Memorandum TM M51-78-08,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Apr. 1978, 90.

● *See **Preface**, page v, for availability of publications marked with dot.*

The United States Navy has several installations located in the seismically active circum-Pacific Belt area. Procedures to quantify earthquake hazards are being developed for buildings, waterfront structures, piers, and drydocks. This report summarizes the procedures developed by the Civil Engineering Lab. to evaluate the earthquake hazard for buildings. Also presented in the report are the results of the seismic vulnerability study for the North Island Naval Station in San Diego. The aim of the study is to quantify the earthquake hazard, to identify buildings that need to be strengthened, modified, or abandoned and to predict what can be expected when a strong earthquake strikes the facility. Emphasis is placed on the development of procedures that are rapid and inexpensive.

The maximum probable ground acceleration at the site was obtained using Monte Carlo methods by placing hypothetical earthquakes on various faults. Variables included the distance from the site to the fault, the magnitude of the earthquake, and its depth of focus. The site response spectra were developed by scaling selected response spectra of available earthquake records. Most procedures for the task were computerized. Considerable time was spent on site visits and the identification of critical buildings. From the available data, simple mathematical models were formulated for each building according to its mass distribution and stiffness characteristics. Yield and ultimate strength capacities and appropriate damping and ductility factors were determined for each building. Damage estimates for each building were made. Damage estimates were determined for 25 buildings to quantify seismic risk for hypothetical earthquakes according to NAVFAC criteria. In addition, damage estimates were made for earthquakes with maximum ground accelerations between 0.05 and 0.50 g at the site. The total replacement cost of the buildings analyzed is $54 million. Using the NAVFAC criteria with a maximum ground acceleration of 0.25 g, the results indicate a damage estimate of about 60% of the replacement cost of the buildings as a group. It is recommended that the most susceptible buildings be analyzed in detail to determine the modifications and strengthening needed.

● 7.3-54 Lew, T. K. and Takahashi, S. K., **Seismic investigation requirements for naval facility modernization projects at San Diego: a preliminary analysis,** *Technical Memorandum TM51-78-01,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Mar. 1978, 53.

The objectives of this study are to provide: (1) approximate guidelines on the seismic adequacy of typical building types at the Naval Station, the Naval Training Center, and the Naval Air Station in North Island, San Diego; (2) guidelines on requirements for seismic investigations in modernization projects; and (3) rough estimates of the rehabilitation cost for project submittals. The method and evaluations presented in this report are intended solely for determining the necessity of performing a seismic safety evaluation before a modernization project. That the method used does not require a seismic safety investigation does not mean that the structure satisfies current seismic requirements. Typical buildings at NAVSTA and NTC selected by the Navy Public Works Center (PWC) at San Diego were only inspected visually in this study. Because of an agreement between PWC and Civil Engineering Lab. personnel during an initial conference at San Diego, these buildings were not thoroughly analyzed because of time and funding limitations. Instead, comparisons of the seismic base shear capacity data with the design base shear forces required by the current SEAOC (Structural Engineer's Assn. of California) criteria were made for the typical building types previously studied at naval sites in North Island, Long Beach, Port Hueneme, and Bremerton, Washington. Based on the results of the comparisons, it is concluded that: (1) the adequacy of masonry buildings is questionable, especially in unreinforced buildings constructed before 1971; (2) all the one- and two-story reinforced concrete buildings are adequate although some of those with three or more stories may be inadequate; (3) all the steel buildings are adequate; and (4) most of the wooden buildings are inadequate.

● 7.3-55 Fintel, M., **A discussion on an alternate procedure for earthquake-resistant design of multistory reinforced concrete structures based on inelastic dynamic analysis: why we need it and what it is,** Portland Cement Assn., Skokie, Illinois, 1978, 10.

The recent development of inexpensive two-dimensional inelastic dynamic (response history) analyses, as well as recent laboratory testing programs of structural walls and coupled walls, now make it possible to use new technology in the explicit inelastic dynamic analysis and proportioning of earthquake-resistant reinforced concrete multistory structures based on rational procedures. The traditional empirical method of proportioning earthquake-resistant concrete structures, a method which evolved over the last three decades, was based on the state-of-the-art at each stage and on experience in earthquakes. This method uses equivalent static loads which are smaller than those indicated by inelastic dynamic analyses. An elastic analysis which is poorly representative of inelastic behavior is used to determine member forces. As a consequence, reduced resistances and sometimes excessive ductility details are provided to assure safety. The suggested inelastic dynamic design of a structure uses earthquake accelerograms as loading, inelastic response history analysis to determine member forces, and resistances from tests for proportioning the members. This method represents a total departure from the traditional empirical design approach. While the present seismic codes are applicable to most structures, the explicit inelastic dynamic analysis permits an alternative

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

approach to multistory reinforced concrete building structures of reasonably regular plan layouts for which inelastic dynamic analyses appear to be warranted.

● **7.3-56** Fintel, M. and Schultz, D. M., **Structural integrity of large panel buildings,** *Journal of the American Concrete Institute,* **76,** *5,* Title No. 76-27, May 1979, 583-620.

This paper reviews the various methods to reduce risk from abnormal loads. To limit the occurrence of progressive collapse in large panel residential structures, a philosophy for establishing general structural integrity is developed to assure bridging of local damage while maintaining overall stability, thus eliminating the need to design for any particular abnormal load. In this approach, the tensile continuity and ductility of the elements, as well as of the overall structure, are provided. The rationale for a minimum tie system consisting of transversal, longitudinal, vertical, and peripheral ties to establish this general structural integrity is developed. The objective of this approach is not to afford absolute safety for any exceptional event in any part of every building, but to limit and substantially reduce the general risk of collapse.

● **7.3-57** Hendry, A. W., **Summary of research and design philosophy for bearing wall structures,** *Journal of the American Concrete Institute,* **76,** *6,* Title No. 76-33, June 1979, 723-737.

Following the Ronan Point accident in 1968, a considerable amount of research work was carried out in the United Kingdom to assess the liability of bearing wall structures to progressive collapse. The research included tests on full-size structures and load-bearing elements. This paper summarizes these investigations and discusses the measures developed to prevent the occurrence of progressive collapse in bearing wall structures at the design stage.

● **7.3-58** Paulay, T., **Developments in the design of ductile reinforced concrete frames,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, 35-48.

A step-by-step summary of the application of a recently published capacity design philosophy, as applied to earthquake-resisting ductile reinforced concrete frames, is presented. The theoretical inelastic dynamic response of three prototype frames, designed by the method and subjected to particularly severe seismic excitations, is then reported. It is shown how the predicted maximum actions compare with those used in the design. The design quantities, derived from a modified conventional elastic frame analysis for a code-specified lateral static loading, were found to ensure a very high degree of protection against hinging in columns at and above the first floor in an economical and practical manner.

● **7.3-59** Ishiyama, Y., **A proposal of a new aseismic design method for buildings,** Building Research Inst., Japan Ministry of Construction, Tsukuba-Gun, 1979, 12.

The seismic-resistant design method presented in this proposal concerns buildings not higher than 60 m. Buildings designed according to this method should sustain almost no damage from moderate earthquakes which might occur several times during the service life of the building, and should not collapse nor cause human casualty in a large magnitude earthquake such as might occur once at most.

● **7.3-60** Karrh, B. R. and Lew, T. K., **Seismic analysis of Building 300 at Long Beach Naval Shipyard, Long Beach, California,** *Technical Memorandum 51-78-25,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Nov. 1978, 36.

The seismic analysis presented in this report is part of a program to reduce the seismic vulnerability of the Long Beach Naval Shipyard. Results from the preliminary analysis of some important buildings at the shipyard indicated that Building 300 is vulnerable to earthquake ground shaking as prescribed by NAVFAC criteria for naval facilities. Building 300, the Engineering Management Building, is a five-story, steel frame building designed in 1971. The estimated current replacement cost of the building is $7,792,000. Safety from collapse under loading specified by the design earthquake criteria is a major consideration in this study.

The objectives of the study are to determine: (1) the current capability of Building 300 to maintain structural integrity when subjected to maximum earthquake accelerations with a 10% probability of being exceeded in a recurrence interval of 25 yr; (2) the maximum response from loading associated with earthquake criteria; and (3) procedures and cost estimates for proposed modifications to strengthen the building. A mathematical model of Building 300 was developed from the design drawings and subjected to the loading associated with the earthquake response spectra developed according to the NAVFAC criteria for the Long Beach, California, site. The elastic dynamic response of the building model under earthquake ground motions was determined by using the ETABS computer program. Modification concepts for the structural system were developed, and their effectiveness was verified by ETABS. The adequacy of the beam-column connections in the existing building for plastic hinge action was analyzed. Cost estimates were made for the required modifications. Conclusions and recommendations were derived from the results of the analysis. In the determination of the necessary modifications, it was assumed that some permanent damage to the building is acceptable but that collapse of the structural frame is not acceptable and must be prevented. The analyses performed are limited to the linear elastic response of the building. The foundations of the building were examined for possible failure under the earthquake loadings. The lateral forces from the computer analysis for Building 300 were compared with those specified by the Uniform Building Code and the Structural Engineers' Assn. of California.

● **7.3-61** Degenkolb, H. J., Wosser, T. D. and Wyllie, Jr., L. A., **Practical earthquake resistant design of building structures,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 57, 24.

Structural design to resist earthquakes is different from structural design for the more usual forces in that seismic loads are uncertain but much larger than the elastic resistance of a structure; consequently the engineer must be concerned with post-elastic strength, cyclic performance of materials, ductility, and stability near ultimate loads. The amount of lateral force to be provided must be related to the design material strengths and load factors. In recent years, allowable strengths have increased and required seismic loads have also increased. Concrete columns have failed in many earthquakes and normal practices of reinforcing beams and girders have proven to be deficient. As a result, detailing requirements for reinforcing steel have become very stringent when bending of reinforced concrete is used to resist seismic loads. Many architectural portions of a building–such as partitions and exterior walls—completely change the strength characteristics of a structure. When these effects have been neglected by the engineer, failures have resulted. The configuration of the building as determined by the architect often determines its performance in an earthquake, but little attention has been paid to this important aspect. Current building codes and standards, since they are based on elastic analyses of the work performed by the structural engineer, can be quite misleading for some configurations and for the effects of some architectural features. In the past, the flexibility of the building and resulting damage to architectural, mechanical, and other components of a building have largely been ignored, but the damage that has resulted in more recent earthquakes has created more concern for this aspect of design.

● **7.3-62** Igarashi, S. and Ogawa, K., **Studies on kinematic model of steel frames for aseismic design (Part 4: on the optimum volume of structural steels of energy absorption members)** (in Japanese), *Transactions of the Architectural Institute of Japan, 284,* Oct. 1979, 61-68.

The previous paper (Part 3) proposed a method to determine an optimum distribution of the cross-sectional areas of structural members so that the structure sustains uniform plastic deformation in all members during an earthquake. If the situation is such that the distribution of plastic deformation of members is controllable, the magnitude of uniformly distributed plastic deformation depends on the total volume of structural steels used in the structure. Therefore, the volume of structural steels should be determined to limit plastic deformation within allowable values. The present paper describes a systematic approach for determining the volume of structural steels on the basis of the energy absorption capacity of all the structural members and the energy concept introduced by Housner. This paper analyzes internal-work–maximum-strain relationships of a member under monotonic loading. The energy absorption capacity of the member is determined based on the strain when local instability of the plate elements takes place. A convenient method is devised with which it is possible to calculate, without resorting to a dynamic response analysis, a reasonable approximation to the total energy input into a structure under earthquake excitation. The total energy is equal to the input energy resulting from the ground motion and from dead loads. Based upon these calculations and the assumption that the input energy is absorbed equally by all members, an optimum volume of steel in a structure is obtained.

● **7.3-63** Plewes, W. G., comp., **Masonry bibliography 1900-1977,** *MASONRY/CAN-78/1,* International Masonry Inst., Washington, D.C., May 1979, 345. (NTIS Accession No. PB 295 987)

This bibliography is a comprehensive listing of books, magazine articles, and technical and governmental publications published from 1900 to 1977 covering all aspects of masonry, including design and construction descriptions, specifications, cost guides, and architectural trends.

● **7.3-64** Fintel, M. and Ghosh, S. K., **Case study of seismic resistance of a 16-story coupled wall structure using inelastic dynamic analysis and an energy dissipation approach,** Portland Cement Assn., Skokie, Illinois, Apr. 1979, 67.

This paper presents an economical structural solution for an earthquake-resistant 16-story shear wall-type building (almost square in plan) with a pinwheel wall layout located in a severe earthquake area. Economy and structural efficiency have been achieved by detailing the walls for ductility and by coupling some of the walls with highly ductile diagonally reinforced door lintels. The design utilizes inelastic response history analyses to determine the forces and deformations to be used in proportioning the structural elements. Proportioning of the walls and coupling beams to resist the forces and deformations, as determined from the dynamic analyses, was carried out using procedures developed in recent years in analytical and experimental investigations.

● *See **Preface,** page v, for availability of publications marked with dot.*

The structure consists of precast hollow core walls (with continuous vertical reinforcement) and prestressed precast slabs with cast-in-place toppings and horizontal joints, resulting in behavior of the individual (isolated) structural walls similar to that of monolithic walls. A design of the structure by the empirical code approach for the specified quasi-static forces resulted in acceptable shear stress levels in the walls. However, the design resulted in extremely high moments in the individual walls in both orthogonal directions requiring amounts of flexural reinforcement in the walls which could not easily be accommodated. Coupling some of the ductile walls with highly ductile diagonally reinforced door lintels reduced the wall moments to manageable levels. A series of two-dimensional dynamic inelastic response history analyses made it possible to assure a desirable sequence of plastification during an earthquake and permitted optimization of the coupling beam strength so that inelasticity of the diagonals commenced only at twice the design wind load, while the walls were kept elastic in response to the design earthquake. Only for the maximum credible earthquake was inelasticity of the walls utilized.

The selected solution resulted in an economical, all ductile structural wall system having a margin of ductility and shear capacity in the walls to resist the maximum credible earthquake of the construction site. This solution could be developed because two-dimensional dynamic inelastic analyses can now be carried out efficiently and relatively inexpensively, and are thus no longer beyond the realm of practical utilization. The average cost of a computer dynamic analysis in this case study amounted to $17.50 for a night rate run at a not-for-profit computer facility. At standard commercial operations, using daytime runs, the cost would undoubtedly be appreciably higher. Usually, no more than ten runs should be necessary to arrive at desirable combinations between strength and ductility levels for the structural elements. In following this approach, rather than the conventional approach, the designer has to spend some additional effort; however, the amount of this excess effort required is within reason and is probably outweighed by the technical and economic advantages gained.

● 7.3-65 Barrientos, C. and Charnaud, B., **Supervised practical work and reconstruction: an experience of the School of Engineering, University of San Carlos of Guatemala** (Ejercicio profesional supervisado (EPS) de la facultad de ingenieria de la USAC en la reconstruccion, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 17, 22.

● 7.3-66 Aguilar A., E., **Work performed in the investigation program of aseismic materials for popular housing—Faculty of Architecture of the University of San Carlos** (Trabajos realizados en el programa de investigacion de materiales asismicos para vivienda popular de la Facultad de Arquitectura de la Universidad de San Carlos, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 27, 6.

● 7.3-67 Caceres, R. and Asturias, J., **Towards a new strategy of rural development: adequate technology and the 1976 earthquake** (Hacia una nueva estrategia de desarrollo rural: la tecnologia apropriada y el terremoto de 1976, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 30, 26.

New approaches to rural and suburban development were tried in response to the Guatemalan earthquake of Feb. 4, 1976. One of these approaches is called "adequate technology." The main characteristics of adequate technology are (1) the use of intensive labor; (2) relative simplicity; (3) small- and medium-scale projects; (4) low cost; (5) compatibility with local ecology; (6) requires low initial investment; and (7) compatibility with socio-cultural patterns. The paper discusses three examples of the concept of adequate technology as developed in response to the earthquake: (1) experiments with low-cost materials for housing and other rural construction using volcanic sands and lime; (2) low-cost solutions for reuse of residual or waste material in the Guatemalan Highlands; and (3) distribution of low-cost kitchen ranges in order to save wood for fuel and improve health conditions.

● 7.3-68 Earle, D. M., **Roofs of tin in El Quiche; an analysis of a reconstruction program in the highlands of Guatemala,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 28, 12.

After the Feb. 4, 1976, Guatemala earthquake, several aid groups promoted earthquake-resistant house building techniques. This paper investigates the reasons these groups failed to change the way the people in seven municipalities in the department of Quiche build their houses, even though the aid groups distributed nearly 100,000 sheets of lamina (laminated tin with zinc for lightweight roofing).

● 7.3-69 Balcarcel J., M. A. and Orellana A., O. R., **The process of reconstruction in Guatemala** (El proceso de reconstruccion de Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemala Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 16, 59.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **7.3-70** Gandara G., J. L., **The reconstruction of Guatemala and improved adobe** (La reconstruccion de Guatemala y el adobe mejorado, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. I, Paper No. 33, 10.

● **7.3-71** Rossell S., C., **Seismic design of reinforced masonry for Guatemala** (Diseno sismico de mamposteria reforzada para Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 64, 13.

The purpose of this work is to establish criteria for the seismic design of reinforced masonry in Guatemala, and to demonstrate that, in the majority of cases in which reinforced masonry has been used in the country for single- or two-story structures, the standards of the Inst. de Fomento de Hipotecas Aseguradas (FHA) provide for adequate reinforcement. As examples, two reinforced masonry structures of two stories each are designed. The first structure constitutes an example of a residence typically built in Guatemala City. The second structure, a special case, is of unusual form and dimensions in order to subject some members to especially high stress. For both cases, the FHA standards proved to be sufficient with regard to dimensions, materials, and the strengthening of reinforced masonry. Included in the paper are discussions of the seismic design of reinforced masonry structures using the equivalent static load method as specified in the Uniform Building Code and the seismic design of such structures using a dynamic analysis. It is concluded that, although the observance of the FHA standards is sufficient for typical reinforced masonry structures in Guatemala, the equivalent static method provides a good approximation for such cases.

● **7.3-72** Ifrim, M., **Reconstruction and repair after the strong earthquake of March 4, 1977, produced in Bucharest, Romania**, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 69, 15.

This paper discusses the differentiation of the degrees of structural damage caused by earthquakes, principles for consolidation of damaged structures, and a method for testing the efficiency of reconstruction work. Particular attention is focused on the damage to structures during the strong earthquake in Romania on Mar. 4, 1977.

● **7.3-73** Mondorf, P. E. and Asturias, J., **Metropolitan Cathedral of Guatemala—damages caused by the 1976 earthquake and its restoration** (Catedral metropolitana de Guatemala, danos provocados por el terremoto de 1976 y su reparacion, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 63, 36.

Construction of the Metropolitan Cathedral of Guatemala began in 1780. A relatively seismic-resistant neoclassical design was originally planned for the building; however, the design was subsequently modified to provide a baroque structural profile. Rubble masonry and stone were used in the construction. In 1917, an earthquake caused severe damage, destroying the cupola, the bell towers, and the western front of the facade, all of which were reconstructed in reinforced cement. A reinforced concrete framework was used to strengthen the naves following the event. The 1976 earthquake caused severe cracks in the masonry, and projecting parts of the building suffered considerable damage. In addition, the towers have shifted and subsided; the main and posterior facades have been partially separated from the body of the church by cracks of considerable size; and the supports in the cupola are broken. This paper examines the reasons for the cracks and provides a description of the methods chosen for restoration. Currently under way, the restoration essentially involves the placement of a cross-braced girder between the towers, the placement of prestressed concrete tie beams at different levels, the elevation of the cupola, the reconstruction of the cupola supports, and the restoration of the walls, domes, and pillars.

● **7.3-74** Cismigiu, A. I. and Dogaru, L. C., **Aseismic design of reinforced concrete columns**, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 72, 11.

After two strong Romanian earthquakes (Vrancea 1940 and 1977), a great number of reinforced concrete columns erected between 1925 and 1940 showed fatigue, obvious brittle degradation, and collapse phenomena. Considering concrete degradation as a primary reason for the decrease in structural strength, rigidity, and other structural properties, the authors have established behavior parameters for use in the design of reinforced concrete columns. Examples are shown.

● **7.3-75** Gatti, A., **The anti-seismic joint in pre-fabrication—a new industrial structural frame system**, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 68, 22.

This paper describes a prefabricated structural frame system. The system, which has no modular ties, is suitable for all types of earthquake-resistant construction. To the system can be added prefabricated interior and exterior walls with conduits for circuitry and wiring. Because of the controlled plastic deformation of such conduits, they are beneficial during a high-intensity earthquake.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 7.3-76 Inoue, K. and Nagata, M., **A study on the plastic design of braced multi-story steel frames (Part 4: On the seismic design load factor of strong column-weak beam braced frames)** (in Japanese), *Transactions of the Architectural Institute of Japan, 283,* Sept. 1979, 49-57.

The degrading restoring force characteristics of a bracing member cause a decrease in ultimate strength and an increase in displacement response of braced frames subjected to severe earthquakes. Inelastic behavior of braced frames under seismic loads depends directly on the slenderness ratio of a bracing member (λ) and on the ratio of story shear force to total shear force shared by the bracing (β). To avoid excessive plastic drift, it is necessary in the design process to take into account the degrading restoring force characteristics of a bracing member. This paper describes a procedure to estimate the seismic design load factor as a function of λ and β, and to design strong-column-weak-beam braced frames.

● 7.3-77 Winter, G. and Nilson, A. H., **Design of concrete structures,** McGraw-Hill Book Co., New York, 1979, 647.

This textbook contains the following chapters: (1) Concrete and Reinforcing Steel; (2) Mechanics and Behavior of Reinforced Concrete; (3) Structural Safety; (4) Beams; (5) Slabs; (6) Compression Members: Axial Compression Plus Bending; (7) Footings; (8) Analysis of Continuous Beams and Frames; (9) Reinforced-Concrete Buildings; (10) Precast-Concrete Construction; (11) Prestressed Concrete; and (12) Reinforced-Concrete Bridges. The book also contains a detailed subject index.

● 7.3-78 Lee, D. M. and Medland, I. C., **Base isolation systems for earthquake protection of multi-storey shear structures,** *Earthquake Engineering & Structural Dynamics,* 7, *6,* Nov.-Dec. 1979, 555-568.

This paper studies the effectiveness of a wide range of bilinear hysteretic isolation systems for shielding multistory 2-D shear structures from earthquake excitation. Important parameters of the isolation systems are identified and their effect on structural response noted. It is shown that isolation systems can be constructed which allow the structure proper to remain purely elastic even during very strong ground motions. It is further shown that the shear responses and base displacements of structures on these isolation systems can be accurately estimated from the elastic response spectra of the forcing earthquakes. The philosophy of structural isolation is discussed and an introduction given to the physical devices currently available to provide it.

● 7.3-79 Smilowitz, R. and Newmark, N. M., **Design seismic accelerations in buildings,** *Journal of the Structural Division, ASCE,* **105**, *ST12,* Proc. Paper 15066, Dec. 1979, 2487-2496.

A procedure is presented for determining the design distribution of story shears and overturning moments in buildings subjected to strong ground motions, with particular emphasis on tall buildings. A parametric study was conducted and modal analyses were performed to determine the influence of the following variables on the most probable response to earthquake excitation at various levels in a building: (1) The type of structural behavior, ranging from that of a purely flexural beam to that of a purely shear beam; (2) the fundamental frequency relative to the intersection of the linear branches of the response spectrum; (3) the degree of structural setback, ranging from uniform to setback over 80% of the height; and (4) the degree of foundation compliance. For all parametric combinations, a bilinear response spectrum was used and the secondary P-Δ effects were incorporated into the modal analysis.

● 7.3-80 **Precast elements, fast-track construction create an operating plant in 6 1/2 months,** *Concrete International,* 1, *4,* Apr. 1979, 34-38.

This paper describes the design and construction of a concrete plant in Anchorage, Alaska, which was built and in operation in only 6 1/2 months. Precast concrete was selected as the building material because of the frigid weather and an accelerated construction schedule. Load-bearing, precast wall panels were used as shear walls for resisting wind and seismic forces.

● 7.3-81 Fintel, M. and Annamalai, G., **Philosophy of structural integrity of multistory load-bearing concrete masonry structures,** *Concrete International,* 1, *5,* May 1979, 27-35.

A philosophy of design establishing minimum detailing criteria to ensure structural integrity of multistory load-bearing concrete masonry structures in their response to the effects of abnormal loads is discussed qualitatively. A system of horizontal ties, vertical ties, dowel bars, and lateral links is developed to provide tensile continuity so that the structure can establish arch, deep beam, and cantilever mechanisms (alternate path) and thus bridge local damage while retaining overall stability. A simplified method for the analysis of tie forces is presented.

● 7.3-82 Yao, J. T. P., **Damage assessment and reliability evaluation of existing structures,** *Engineering Structures,* 1, *5,* Oct. 1979, 245-251.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

This paper examines various definitions of structural damage; reviews available methods for damage assessment; and discusses new methodologies for the reliability evaluation of existing structures. In the latter case, data determined from full-scale dynamic tests are analyzed.

● 7.3-83 Adams, P. F., **Overall stability considerations in the design of steel structures,** *Engineering Structures,* 1, 5, Oct. 1979, 236-244.

Generally, the analyses used to determine the distribution of bending moments and internal forces in a structure are first-order analyses. Such analyses neglect the so-called *P*-Δ effects (the effects produced by the vertical forces acting through the laterally deflected position of the structure); thus, the stiffness and strength of the structure are overestimated. The design procedure described in this paper recognizes this neglect. First a structure is classified as either "sway prevented" or "sway permitted." For either case, the forces and moments predicted by the first-order analyses are translated into member sizes through the use of "interaction equation." In the sway-permitted condition, however, these equations are adjusted to require an increase in column size to attempt to account for the neglect of the *P*-Δ effects. In the *P*-Δ method of design, the secondary forces, produced by the vertical loads acting through the laterally displaced shape of the structure, are included directly in the analysis. This approach removes the artificial distinction between a sway-prevented and a sway-permitted structure, which is implied by the present "*K*-factor" design approach to columns, and leads to a more rational technique for the design of columns and bracing systems.

● 7.3-84 Bates, F. L., Farrell, W. T. and Glittenberg, J. K., **Some changes in housing characteristics in Guatemala following the February 1976 earthquake and their implications for future earthquake vulnerability,** *Mass Emergencies,* 4, 2, Nov. 1979, 121-133.

The data discussed in this paper show that considerable change has taken place in housing characteristics in Guatemala since the 1976 earthquake. In the two years following that event, houses have changed from the typical adobe structure with a tile roof, characteristically found in ladino communities in eastern Guatemala before 1976, to houses made of materials considered by most people to be safer in an earthquake. Roofs are lighter and made of lamina or duralita instead of tile, and walls are made of materials such as wood, concrete block, terrecreta, or a combination of these and other lighter, more flexible materials. This substitution of other materials for adobe and tile has undoubtedly improved the seismic safety of houses. It must be recognized, however, that the way materials are used to create an integrated structure is perhaps more important to earthquake resistance in housing than the materials used. At this stage of analysis, no firm conclusions can be drawn concerning improvements in structural integrity. It can be stated, however, that, in the case of houses built by reconstruction agencies, care has been exercised to provide a seismic-resistant design and to use seismic-resistant construction techniques. Because the reconstruction process is still in progress, and because the obsolescence in housing, coupled with population growth, will lead to continual house construction, it is impossible to say whether the trend toward the use of more earthquake-resistant housing will continue indefinitely. The changes that have occurred in housing are the result of a combination of individual efforts and agency programs. Individuals seem to be moving away from traditional housing designs towards the use of more safe materials even when not directly assisted by agencies. This movement is away from indigenously produced local materials towards materials requiring industrial manufacture.

It is difficult to summarize the attitudes of the people interviewed in this study towards the reconstruction process. On the one hand, they seem to be pleased with the amount and type of aid they received. On the other, they seem to be dissatisfied with some of the procedures and organizational structures established to render assistance to them. There also appear to be differences of opinion about the underlying equity of the principle employed as a basis for distribution. Finally, the amount of satisfaction or dissatisfaction with aid seems clearly to be associated with the size of community and perhaps with the type of agency program utilized in that community.

● 7.3-85 Gupta, S. P., **Recent earthquake damages and earthquake resistant construction of small buildings in India,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 485-494. (For a full bibliographic citation, see Abstract No. 1.2-21.)

Unengineered construction such as mud, stone rubble masonry, and brick houses have experienced maximum damage in some of the most recent earthquakes in India. Most of the population of the country lives in houses of these types. This paper deals with the construction practice in India for such small dwellings and surveys damage caused in the most recent earthquakes in India. Methods for strengthening such construction in order to improve the earthquake resistance are outlined. The results of a study of a brick model are given, and the reinforcement detailing requirements for small buildings are provided.

● 7.3-86 Eaton, K. J., **Low income housing in seismic zones,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 458-473. (For a full bibliographic citation, see Abstract No. 1.2-21.)

This paper highlights many of the practical building problems that exist when low-income housing is constructed in developing countries that experience earthquakes. Various forms of construction are examined and both good and bad design points are identified. Consideration is given to means for minimizing the consequences of an earthquake and in particular a detailed list of guidelines and practical hints for various methods of construction are given. It is pointed out that there is a necessity to incorporate some of these rules in appropriate seismic design codes and regulations, and it is concluded that satisfactory earthquake-resistant low-income houses can be constructed provided they are well designed and built.

● 7.3-87 Key, D., **Earthquake resistant structures in the Caribbean: design practice, costs and problems,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 345–364. (For a full bibliographic citation, see Abstract No. 1.2-21.)

● 7.3-88 Bhatti, M. A., **Optimal design of localized nonlinear systems with dual performance criteria under earthquake excitations,** *UCB/EERC-79/15,* Earthquake Engineering Research Center, Univ. of California, Berkeley, July 1979, 110. (NTIS Accession No. PB 80 167 109)

This report presents a formulation for the earthquake-resistant design of localized nonlinear systems. Based upon the current design criteria, two levels of performance constraints are imposed as follows. For small earthquakes which occur frequently, the structure is constrained to remain elastic with no structural damage. For a large earthquake, the structure can undergo inelastic deformations at known locations of nonlinearities, with limited damage. The problem is formulated as a min-max problem, and a general strategy to transcribe it to the canonical form of a nonlinear programming problem is given. An algorithm of the feasible directions type is given to solve the resulting nonlinear programming problem. The general techniques are applied to the design of nonlinear energy-absorbing devices, which are part of an earthquake isolation system for many types of buildings. Several design problems with different performance criteria are considered and the results compared to see the effect of these different criteria. Comparison is also made with results reported earlier with only one level of constraints. The results clearly show the effectiveness of the present approach with dual performance criteria over the conventional single criterion approach.

7.3-89 Lyudkovskii, I. G., Fedorov, A. D. and Malkov, Yu. B., **Experience in the construction of a suspended reinforced concrete shell** (Opyt striotel'stva visyachei zhelezobetonnoi obolochki, in Russian), *Beton i zhelezobeton, 9,* Sept. 1979, p. 16.

The paper relates experience in the design and erection of a concave suspended prestressed reinforced concrete shell, with cutout for a skylight, as cover for a market place in Angarsk, a location with sub-Arctic temperatures and 7-point seismicity. Studies of the prestressed state of the suspended shell on a full-scale model are discussed, along with the computational model used and the number and placement of guy cables.

7.3-90 Spivak, N. Ya. et al., **Lightweight concrete residential construction in seismic districts** (Legkobetonnoe domostroenie v seismicheskikh raionakh, in Russian), *Beton i zhelezobeton, 6,* June 1979, 3–5.

The paper discusses the effective use of concrete with porous aggregate in earthquake-resistant construction. Test results are reported on full-scale portions of multistory buildings using such concretes. Results attest to excellent ability on the part of the concretes tested to withstand high-intensity dynamic effects.

7.3-91 Vyzhigin, G. V., Durneva, R. N. and Yampol'skii, L. S., **The outlook for improved structures in multistory industrial buildings in earthquake-prone areas** (Perspektivy sovershenstvovaniya konstruktsii mnogeotazhnykh promzdanii dlya seismicheskikh raionov, in Russian), *Beton i zhelezobeton, 6,* June 1979, p. 6.

The paper describes proposed improvements in the design of multistory industrial buildings. The proposals are geared to cutting down on the amount of steel and concrete needed, deciding on suitable, easily fabricated, and easily erected structural members for regions of different seismic risk, and improving the performance and the esthetic features of the structures.

7.3-92 Kimberg, A. M., Zavriev, K. A. and Bychenkov, Yu. D., **A prestressed prefabricated frame for earthquake-resistant buildings** (Prednapryazhennyi sbornyi karkas seismostoikikh zdanii, in Russian), *Beton i zhelezobeton, 6,* June 1979, 7–8.

The paper describes designs of a prefabricated prestressed frame for earthquake-resistant buildings. Tension loading of reinforcements is applied at the construction site in joining cross-beams to columns. Engineering cost data are provided for the designs. A brief description is provided of research work on the earthquake-resistant certification of buildings.

7.3-93 Bediashvili, M. A. et al., **Experience in the design and construction of buildings with earthquake-resistant structural members in Kirghizia** (Opyt proektirovaniya i stroitel'stva zdanii s seismostoikimi konstruktsiyami v Kirgizii, in Russian), *Beton i zhelezobeton, 6,* June 1979, 8–9.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

Production experience with series IIS-04 standard reinforced concrete structural members for frame panel buildings is described. Details of a beam-column joint are provided. Applications in public buildings 7 to 9 stories high are mentioned. Savings in structural materials are claimed (10-12% for steel, 8-10% for concrete).

7.3-94 Makhviladze, L. S., **A large-panel dwelling prestressed during construction** (Krupnopanel'nyi dom s prednapryazheniem pri montazhe, in Russian), *Beton i zhelezobeton, 6,* June 1979, 10-11.

The paper discusses a new method for erecting large wall panels that are prestressed after erection. Also discussed are design solutions for the inner and outer wall panels and their joints. Joint details, rigging and erection accessories, and tensioning devices are described. The improvements provide greater sturdiness in fabrication, transportation, and erection, with greater resistance to seismic loads.

7.3-95 Bediashvili, M. A. and Bychenkov, Yu. D., **Frame-panel structures for multistory earthquake-resistant construction** (Karkasno-panel'nye konstruktsii dlya mnogoetazhnogo seismostoikogo stroitel'stva, in Russian), *Beton i zhelezobeton, 1,* Jan. 1979, 11-13.

Improved design solutions are reported for the standard IIS-04 line of reinforced concrete frames. Details of floor-column and beam-column joints are shown, along with details of the tying of beams and the arrangement of the double-row reinforcements in the beams. Stiffening diaphragms can be placed longitudinally or transversely and the frames can be used in buildings of from 5 to 16 stories in height. The frames are designed for use in public and commercial buildings, hospital and health clinics, schools and kindergartens, and industrial administrative buildings in various earthquake-prone regions of the U.S.S.R.: The Georgian Republic, Armenia, Moldavia, Tadjikistan, Uzbekistan, the Black Sea coastline of the Caucasus, and some highly seismic areas of eastern Siberia.

7.3-96 Martem'yanov, A. I., **Calculations and design of farm buildings extended in plan** (O raschete i konstruirovanii protyazhennykh v plane sel'skokhozyaistvennykh zdanii, in Russian), *Beton i zhelezobeton, 6,* June 1979, 19-20.

The paper singles out features of the design of loadbearing reinforced concrete single-story frame farm buildings for which the lineal extent must be taken into account in relation to seismic conditions. Examples of recent earthquake damage to farm buildings are contrasted to the survivability of earthquake-resistant aviaries under the same conditions. Exact analytical formulas for damped and undamped earthquake-induced motion of farm structures are presented.

● 7.3-97 Degenkolb, H. J. and Wyllie, Jr., L. A., **Design and ductility of shear walls,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 306-344. (For a full bibliographic citation, see Abstract No. 1.2-21.)

● 7.3-98 Reinhorn, A. and Gluck, J., **Torsional coupling in antiseismic design of tall buildings,** *256,* Faculty of Civil Engineering, Technion-Israel Inst. of Technology, Haifa, June 1979, 42.

This paper summarizes the principal effects of dynamic torsional coupling, emphasizes the main structural parameters influencing such behavior, provides guidelines for evaluation of equivalent seismic loads, and discusses the limitations of the static design approach.

● 7.3-99 **Structural design of tall concrete and masonry buildings,** *Monograph on Planning and Design of Tall Buildings, CB,* American Society of Civil Engineers, New York, 1978, 938.

This volume presents topics of particular interest to designers of concrete or masonry tall buildings. It is assumed that the readers will have a working knowledge of the theory and design practices for reinforced and prestressed concrete and masonry, and no attempt is made to reproduce basic design concepts, codes, or handbook material in this volume.

The volume is divided into four major divisions, each composed of several chapters. The divisions present information on the selection, analysis, and design of tall concrete and masonry buildings. The divisions and chapter titles follow: Division I—Introduction; CB-1—Characteristics of Concrete and Masonry Tall Buildings; CB-2—Design Criteria and Safety Provisions; Division II—Selection of Concrete Structural Systems; CB-3—Concrete Framing Systems for Tall Buildings; CB-4—Optimization of Tall Concrete Buildings; Division III—Analysis of Tall Concrete Buildings; CB-5—Elastic Analysis; CB-6—Nonlinear Behavior and Analysis; CB-7—Model Analysis; CB-8—Stability; CB-9—Stiffness, Deflections, and Cracking; CB-10—Creep, Shrinkage, and Temperature Effects; Division IV—Design of Tall Concrete and Masonry Buildings; CB-11—Design of Cast-in-Place Concrete; CB-12—Design of Structures with Precast Concrete Elements; CB-13—Design of Masonry Structures. Included in the volume are a glossary, a bibliography, a list of contributors, and building, name, and subject indexes.

● 7.3-100 **Structural design of tall steel buildings,** *Monograph on Planning and Design of Tall Buildings, SB,* American Society of Civil Engineers, New York, 1979, 1057.

● *See **Preface**, page v, for availability of publications marked with dot.*

This volume is a comprehensive record of the understanding held by a number of leading structural engineers of the behavior of tall steel buildings, their views as to how to design them, and their impressions as to what is to come. It is intended as a reference and guide to the principles of such design.

The chapter titles follow: SB-1—Commentary on Structural Steel Design; SB-2—Elastic Analysis and Design; SB-3—Plastic Analysis and Design; SB-4—Stability; SB-5—Stiffness; SB-6—Fatigue and Fracture; SB-7—Connections; SB-8—Load and Resistance Factor Design (Limit States Design); SB-9—Mixed Construction. Included in the volume are a glossary, a bibliography, a list of contributors, and building, name, and subject indexes.

7.3-101 Aizenberg, Ya. I. et al., **Adaptive system for earthquake-proofing of structures** (Adaptivnye sistemy seismicheskoi zashchity sooruzhenii, in Russian), Nauka, Moscow, 1978, 246.

The book presents research findings on the seismic response and the reliability of adaptive earthquake-proofing systems. The discussion includes seismic risk and reliability of systems with redundant members subjected to narrowband or wideband seismic processes. Results are reported on experimental investigations of systems with disengaging joints and limit points. Methods are presented for calculations and design of tall structures with vertically deployed disengaging joints.

7.4 Design and Construction of Nuclear Facilities

● 7.4-1 Aziz, T. S., Duff, C. G. and Tang, J. H., **Seismic qualification of pressure relief valves for a negative containment system,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 395-424.

A few nuclear power stations designed and built in Canada (for example, Pickering Generating Station) utilize a multi-containment arrangement with a common vacuum building to provide a negative pressure containment envelope should a postulated accident occur in one of the containments. In the event that the pressure in one of the containments rises to a certain level, the pressure relief valves which are located in a vacuum duct joining the different containments to the vacuum building will open to relieve the pressure to the vacuum building, where a spray system is actuated to condense the incoming steam. These safety-related valves should remain intact and operational and cause no loss of containment following a design basis earthquake (DBE). In this paper, the basis of the seismic qualification of these valves by a nonlinear transient dynamic analysis is presented. The nonlinear analyses take into consideration the behavior of the piston during opening and accounts for such factors as piston rocking and sway effects, diaphragm folding, eccentricity of the center of the mass and the center of rigidity, and the nonlinearities generated by gaps and friction in the system. Response quantities such as accelerations, displacements, rotations, diaphragm forces, and opening time during a design basis earthquake are obtained. The results of the different analyses, as related to the functional operability of the valves, are evaluated and discussed.

● 7.4-2 Mehta, D. S. and Lee, K., **Code specifications and regulatory requirements for seismic design, analysis and testing of structures, components & systems,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 289-300.

This paper provides a brief summary of United States codes, standards, and applicable government regulatory requirements used in the design of safety-related structures, components, and systems for nuclear power plants. It also describes the requirements established for the seismic design of associated building structures.

● 7.4-3 Lu, T. D., Patil, U. and Fischer, J. A., **Seismic analysis of mechanical engineering equipment,** *Engineering Design for Earthquake Environments,* Paper No. C188/78, 177-184. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The details and results are presented of a seismic qualification analysis for a lubricating oil system consisting of air-cooled heat exchangers. This equipment is modeled as a series of discrete nodal points interconnected by beam-column and truss elements. The modeling concepts, details and assumptions are also presented. The seismic response of the system is analyzed by means of a response spectrum method. The calculated seismically induced displacements and stresses are used to evaluate the structural integrity and performance of the equipment.

● 7.4-4 Heidebrecht, A. C., **Seismic qualification of equipment mounted in CANDU nuclear power plants,** *Engineering Design for Earthquake Environments,* Paper No. C185/78, 149-156. (For a full bibliographic citation, see Abstract No. 1.2-2.)

This paper concerns the test procedures used in seismic qualification of CANDU (CANada Deuterium Uranium) nuclear power plants. A draft standard, CSA (Canadian Standards Assn.) N289.4, is in preparation and comments are made on some of the major aspects of the standard. A detailed evaluation of the single frequency testing procedures is presented, followed by several case

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

histories in which this procedure has been used. The paper concludes by discussing current research in this field and proposes directions for future research.

● 7.4-5 Khan, A. S. et al., **Analysis and design of seismic Category I thin sheet structures,** *Engineering Design for Earthquake Environments,* Paper No. C181/78, 111-118. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The design criteria for seismic Category I thin-sheet structures and restraints in nuclear power plants are presented. Structural design considerations, loads, load combinations, design allowances, and analytical methods for the design and analysis of such structures and their restraints are also presented. The analytical methods presented include procedures for analysis of thin structures subjected to internal negative pressure and to seismic and gravity loads. The stresses resulting from negative pressure and seismic loads in the sheet deformation mode and stresses resulting from gravity and seismic loads in the beam deformation mode are combined and kept within what is allowed by the American Iron and Steel Inst. code. The seismic loads are calculated from seismic accelerations corresponding to the system frequency of the structure and its restraints, in the beam deformation mode, and corresponding to the system frequency of the sheet and stiffener, in the sheet deformation mode.

● 7.4-6 Masri, S. F., Richardson, J. E. and Young, G. A., **Evaluation of seismic analysis techniques for nuclear power plant piping and equipment,** *Engineering Design for Earthquake Environments,* Paper No. C178/78, 75-90. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The development of efficient and reliable methods for calculating the seismic forces on piping and equipment critical to nuclear power plant safety has been the subject of numerous studies. To evaluate the procedures currently used for deriving piping and equipment design spectra, this paper reviews U.S. Nuclear Regulatory Commission requirements; discusses considerations that arise in the seismic-resistant design of equipment and structure systems, such as characterization of earthquake inputs and modeling of equipment and structure systems; and assesses calculation techniques of in-structure response spectra. Significant conclusions of recent pertinent literature are included.

● 7.4-7 Plichon, C. and Jolivet, F., **Aseismic foundation system for nuclear power stations,** *Engineering Design for Earthquake Environments,* Paper No. C190/78, 193-205. (For a full bibliographic citation, see Abstract No. 1.2-2.)

A foundation system, facilitating the construction of standard nuclear power plants in areas exposed to strong earthquakes, is described. The system consists of a device that is interposed between the buildings of a nuclear power plant and the soil in order to limit the horizontal accelerations in the buildings. The foundations are composed of double rafts with seismic-resistant bearings that are placed between the upper and lower parts of the rafts. The bearings are composed of a block of reinforced elastomer and, if needed, a set of friction plates such as stainless steel and leaded bronze plates. Three nuclear power plants are being constructed with this system.

● 7.4-8 Kauffmann, F., Bonnefoy, A. and Fougeres, D., **Seismic qualification of an emergency diesel generator and of its auxiliaries,** *Engineering Design for Earthquake Environments,* Paper No. C187/78, 169-175. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The general seismic qualification procedure used for an emergency diesel generator and its auxiliary components is described, and the major simplifying assumptions used in the study are discussed. Typical applications of the procedure and particular engineering problems are presented. Only the components that can be qualified primarily by analysis are treated.

● 7.4-9 Fardis, M. N., Cornell, C. A. and Meyer, J. E., **Accident and seismic containment reliability,** *Journal of the Structural Division, ASCE,* **105,** *ST1,* Proc. Paper 14305, Jan. 1979, 67-83.

An integrated reliability study of the containment vessel of a nuclear power plant is presented. The focus is on features of seismic and accident-related behavior that may affect adversely the containment safety role. The behavior is described probabilistically under a range of accident and seismic conditions extending far beyond design levels. The individual effects of seismic and accident events are analyzed, as is the coupling of those effects for the various possible timings of the causative events. Reliability estimates are obtained by combining probabilistically described damage with a probabilistic description of the causative events. A large number of uncertainties are included, and the final reliability estimates reflect the total uncertainty—including the statistical component—faced by the safety analyst.

● 7.4-10 Shibata, H. and Okamura, H., **An evaluation method of system failure of industrial facilities under seismic loading,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 407-426.

This paper treats the basic idea for evaluating the probability of failure of industrial facilities, especially nuclear power plant equipment and piping.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **7.4-11** Lee, M. C. et al., **Seismic performance of piping systems supported by nonlinear hysteretic energy absorbing restrainers,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 156-164.

Selected results are presented of an investigation into the desirability of using solid-state, nonlinear, hysteretic energy-absorbing restrainers as the supporting elements for nuclear power plant piping systems. The results have been generated for three cases representing simple piping systems, namely, linear pipes with linear restrainers, linear pipes with elasto-perfectly plastic restrainers, and linear pipes with Ramberg-Osgood-type restrainers. Realistic seismic response produced at typical support points within the main structure of a power plant is used as the input excitation to the support restrainers. Dynamic time histories of response have been determined for each case over prescribed ranges of the critical parameters and the significant results have been correlated. The results show that nonlinear energy-absorbing restrainers can be very effective in reducing seismic forces in piping systems, without excessive yielding, provided the restrainers are properly designed. Restrainers of the Ramberg-Osgood type have been found to be very effective when the characteristic parameters are properly controlled. Based on the results of the overall investigation, it is concluded that nonlinear hysteretic energy-absorbing restrainers can improve the seismic performance of nuclear power plant piping systems resulting in cost savings and enhanced safety.

● **7.4-12** Johnson, J. J. and Kennedy, R. P., **Earthquake response of nuclear power facilities,** *Journal of the Energy Division, ASCE,* **105,** *EY1,* Proc. Paper 14296, Jan. 1979, 15-32.

The differences between the design of nuclear facilities and conventional structures are discussed in this paper. The seismic design process begins with site investigation. Two design earthquakes, the operating basis earthquake (OBE) and the safe shutdown earthquake (SSE), are determined from a study of historical seismicity, geology, and tectonics. The OBE has a reasonable probability of occurrence during the design life of the facility. The SSE is based on maximum earthquake potential for the site. Conventional structures are commonly designed only for earthquake levels corresponding to the OBE. For these structures, ductile inelastic behavior is considered acceptable. Nuclear facilities are designed to remain elastic under the greater SSE loading. Seismic analysis is performed in phases beginning with overall analysis of the structure and soil to determine gross motions. Soil-structure interaction is analyzed by either the impedance function approach or the finite element method. Response from this analysis is used for more detailed analyses of structures or components. Ultimately, all structures and components necessary for safety are seismically qualified by analysis or testing.

● **7.4-13** Suta, B. E. et al., **Annotated bibliography: hazard assessments for the geologic isolation of nuclear wastes,** *Center for Resource and Environmental Systems Studies Report 41,* SRI International, Menlo Park, California, Nov. 1977, 187.

This annotated bibliography contains materials concerning risk assessments pertinent to constructing, operating, and decommissioning a federal repository for the geologic isolation of radioactive waste. A risk is considered to encompass both the likelihood and the actual adverse consequences of an event. Continuous events, such as wind erosion or leaching, and episodic events, such as earthquakes or sabotage, are included. The material presented is intended to aid in the preparation of risk analyses, safety analyses, and environmental impact reports. A prospective federal repository is to be constructed and operated under the National Waste Terminal Storage Program of the Energy Research and Development Admin. Radioactive waste to be accepted for disposal in federal repositories may include all commercially generated high-level waste, cladding hull waste, intermediate-level waste, and transuranic and low-level waste. Options include disposal of unprocessed spent fuel elements and disposal of PuO_2. In the latter case, the PuO_2 may be either mixed with the high-level waste or packaged separately in canisters for disposal. These wastes will be received at surface facilities designed to handle and prepare the various categories of wastes for storage. Radioactive wastes will be disposed of by placing waste containers in an underground storage area excavated in a suitable geologic formation. The storage tunnels will be backfilled with excavated material and, at decommissioning, the entire facility will be backfilled and sealed.

● **7.4-14** Chinnery, M. A., **Investigations of the seismological input to the safety design of nuclear power reactors in New England,** Lincoln Lab., Massachusetts Inst. of Technology, Lexington, Jan. 1979, 72.

This report reviews and assesses the available literature on the determination of maximum possible earthquakes. An attempt was made to find evidence of the upper bounds of earthquakes based on data garnered from earthquake catalogs, such as the catalog of the International Seismological Centre. It was found that the determination of the upper bounds of earthquakes was not possible because of the severe limitations imposed by incomplete reporting and magnitude scale saturation.

● **7.4-15** Petrina, P., Sexsmith, R. and White, R. N., **Safety analysis of nuclear concrete containment structures,** *NUREG/CR-1097,* Div. of Reactor Safety Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Dec. 1979, 176.

● *See* ***Preface****, page v, for availability of publications marked with dot.*

The safety of a structure subjected to various loads may be most rationally described by assessing the probability of failure for each of the loading events. Both the loading and the carrying capacities of a structure are random variables. Accordingly, the most meaningful criterion for the evaluation of structural safety should be based on probabilistic considerations. A major obstacle in probabilistic analysis derives from the incomplete definition of the probability distributions of the relevant random variables, particularly in the regions of rare occurrences. Consequently, current methodologies for reliability-based design of structures are often formulated in terms of estimates of moments of the distributions of the random variables, normally by means of second-moment formats, in which only the means and the covariances are considered.

The objective of this work is to present a procedure for calculating the reliability of a concrete containment structure in terms of a safety index when the random variables entering into the design equations are defined by their probability distribution function. This is accomplished by means of mapping the random variables into standardized Gaussian variables. The evaluation of the safety index is greatly facilitated by selecting a polynomial function to approximate the transformed variable. The proposed approach provides a means for extension of the reliability index from second-moment formats towards a probabilistic format. The procedure is illustrated for a post-tensioned concrete containment structure considering failure modes typical of those for cylindrical shells. Selected design cases involving structural loads caused by the seismic motions and the loss-of-coolant accident are treated. In addition, this work includes a brief assessment of failure modes and an evaluation of uncertainties in physical properties of materials and load parameters. A Monte Carlo simulation method was used to predict the stochastic response characteristics of concrete containment considering the effect of the randomness of the soil characteristics and concrete stiffness. This study provides a basis for developing a procedure for a more rational selection of load factors for the loads considered in current design equations. This in turn will ensure an efficient design at a preselected level of safety.

● **7.4-16** Der Kiureghian, A., **A reliability based investigation of design factors, topical report**, Agbabian Assoc., El Segundo, California, 1978, 152.

In this report, second-moment probabilistic techniques are used to formulate structural resistances and loads and to derive reliability-based safety, load, and strength factors for design. Existing concepts of the second-moment reliability theory have been extended to the practical case of multiple load combinations. This development consistently includes the stochastic character of loads and the unpredictable nature of their combinations. For this purpose, a new technique for the evaluation of load combinations is presented, whereby the moments of the extreme of combined loads are obtained in terms of the moments of individual loads and the parameters describing their random fluctuations in time. Reliability-based safety, load, and strength factors are derived in terms of the acceptable level of risk, the coefficients of variation of the loads and resistance, uncertainties associated with errors in modeling and estimation, and a set of parameters describing the stochastic nature of loads and their combinations. Two distinct formulations of these factors are presented. A numerical example is provided wherein the values of the factors for a number of specific assumptions are determined and the significance of various design variables on the reliability-based factors are examined. In the light of the theoretical formulations in the report, current deterministic design procedures are critically examined. Specific inconsistencies and inadequacies in these procedures are determined. It is shown how the proposed theory can be used to improve or further refine the present design methods.

● **7.4-17** Xercavins, P., **Bearings for earthquake resistant structures**, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 67, 10.

An investigation undertaken after the 1976 Guatemala earthquake has shown that an important number of structures placed on traditional roller bearings suffered severe damage and became unserviceable while structures on correctly placed elastomeric bearings remained serviceable throughout the critical period. The Incienso Bridge is a good example of the latter case. This confirms once more the superiority of elastomeric bearings over traditional ones for structures designed to be earthquake resistant, a fact which has induced the French Electricity Board (EDF) to specify elastomeric bearings for nuclear reactors in seismic areas. A type of large-dimension elastomeric bearing, as applied to a number of nuclear reactors built by or in collaboration with EDF in France, South Africa, and Iran, is described. In some cases, the elastomeric bearings were combined with special sliding plates.

● **7.4-18** Kratzig, W. B. and Meskouris, K., **Towards safe and economic seismic design of cooling towers of extreme height**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 8/2, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Nuclear power plants are being increasingly equipped with natural draft cooling towers of heights greater than 160 m. In many arid zones, where high natural draft cooling towers with dry cooling systems are being projected, wind loads are relatively small while site seismicity is relatively high. Thus, the ability of the tower to withstand earthquake-induced forces governs its design. On the other hand, most reinforced concrete cooling towers of extreme height built so far have been designed to withstand high wind loads and moderate earthquake loads. The effects of special structural measures for obtaining an economic design, such as the introduction of ring-stiffened shells, have been studied mainly for those towers. It is the purpose of this paper to analyze the effects of various structural measures and other parameters on the seismic response of such tall cooling towers. As an example, a dry cooling tower 180 m in height on X-supports is chosen. The investigated structural parameters are (1) introduction of ring stiffeners, allowing a decrease in shell thickness while maintaining a high level of buckling safety and (2) variation of the shell support system stiffness. After a preliminary static design for dead load and wind, case studies of the earthquake behavior were conducted to evaluate the influence of these parameters. Results obtained show that the parameters exhibited a marked influence on the earthquake behavior. Strategies for designing the cooling tower for a higher level of safety at little or no additional cost are indicated.

● **7.4-19** Raheja, R. D., Cho, F. L. and Meligi, A. E., **Design of prequalified support systems subjected to dynamic loads**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(b), Paper K 10/6, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes an approach for the design of prequalified system supports under dynamic loads. System supports in safety-related buildings of light water reactors have to be designed to provide structural integrity during and following a dynamic event. The loads that such a system must be designed to withstand are dead weight, thermal, seismic and in addition, for boiling water reactors, safety relief valve blowdown loads have to be considered. To demonstrate the merit of the proposed approach, the authors have chosen the HVAC duct work and their supports as a representative system. An acceptable method to dynamically qualify such a support system is to simulate it as a multidegree-of-freedom model, similar to the conventional approach of idealizing a piping system, which can then be analyzed using either a response spectra or a time-history technique for analysis of the dynamic effects.

The present method is one that prequalifies the system supports and ducts for a certain acceleration level by decoupling the two systems. This approach preselects the maximum spacing of the support system such that the supporting duct work including accessories, will respond in the high or rigid frequency range of the building dynamic response. In addition, the system supports are designed to respond in the rigid frequency domain, thus, eliminating the interaction effects between the two systems. This also ensures that the dynamic response of the decoupled systems are equivalent to that of the combined coupled system.

In the present approach, rectangular ducts are considered and two typical hanger configurations are analyzed. For each of these configurations, three or four typical structural angle members are selected with a combination of hanger member leg lengths, hanger depths, and widths. The latter two parameters represent the duct dimensions. Each of the parameters above are varied in the analysis and a frequency analysis is performed using a standard computer program. The hanger load capacity is determined using a frequency-controlled design which is the basis for design of the structural members and connections. In addition to the dynamic effects transverse to the duct run, it is essential to consider dynamic effects along the duct run. The loads in this direction are transferred using a system of longitudinal cross or K-braces spaced at preselected intervals along the duct axis. Further consideration is given in the design for a duct-to-hanger connection to transfer shear loads into the hanger system.

The capacity of the support system can be increased by a factor of two or more with a slight system design modification. This can be done by introducing internal cross bracing, using a structural bar member, within the duct and along the duct run at each support location. This has been shown to increase the lateral rigidity of the support assembly and thus increases its load-carrying capacity. It can be shown that the slight restriction in air flow and drop in pressure caused by the internal brace, if oriented properly, does not result in a change in duct dimensions for large ducts.

The results of the analysis are presented in the form of load tables and charts for various common structural member sizes and for standard configurations of support systems with a predetermined load capacity under dynamic loads. The convenience of using prequalified system supports for a given duct size results in considerable saving in engineering manhours and computer time that would otherwise be necessary if each system were designed uniquely. This design analysis method provides a convenient tool and is an optimal method for establishing the reliability of component supports without undertaking a rigorous case-by-case design approach. The approach can be extended to other component supports, such as cold piping, cable trays, heaters and coolers, instrument racks, etc. In such a design approach, consideration should be given to the establishment of an appropriate mass frequency ratio and stability criteria between the supporting and supported components.

● **7.4-20** Dong, R. G., **Definition of component and structural fragility for use in the seismic safety margins research program**, *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology*, Vol. K(a), Paper K 3/9, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

● *See **Preface**, page v, for availability of publications marked with dot.*

The Seismic Safety Margins Research Program (SSMRP) sponsored by the U.S. Nuclear Regulatory Commission is to estimate the conservatism in the Standard Review Plan seismic safety requirements and to develop improved seismic requirements. The approach to achieve these objectives is to develop probability methodology that more realistically estimates the behavior of nuclear power plants during an earthquake. The development of descriptions of fragility for components, systems, and structures is a necessary part of this approach, and the Components and Structural Fragilities Project of the SSMRP is responsible for developing these descriptions. The SSMRP will comprise several phases. Phase 1 is addressed at this time, and will focus specifically on the Zion 1 plant and site in Zion, Illinois. A description of fragility for a component, system, or structure characterizes the probability of failure as a function of a load parameter such as stress, strain, and acceleration. Failure is defined as the inability to serve an intended function; e.g., a valve is considered failed if it is unable to open or close, perhaps as a result of body distortion, when it is called upon to do so.

An execution plan for the project has been established. The critical components, systems, and structures will be identified. Information pertaining to design, qualifications, installation, and in-service performance will be gathered. Test data will be collected from nonnuclear as well as nuclear industries and foreign as well as domestic sources. Relevant failure modes will be determined following the gathering of information and data. Descriptions of fragility to be developed will be selected and developed. For Phase 1, the project execution will be based on existing information. The area of fragility is quite developmental, thus a regular exchange of information with knowledgeable people in the area is important. A panel of six persons was formed for this purpose. The first meeting of the SSMRP Fragilities Panel was held on Dec. 13, 1979. This paper summarizes the execution plan for the project and the observations of the panel at the Dec. 13 meeting.

● **7.4-21** Johnson, J. J., **Subsystem response determination for the US NRC Seismic Safety Margins Research Program,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 3/8, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A report on the progress of the structural subsystem response project of the U.S. Nuclear Regulatory Commission's Seismic Safety Margins Research Program (SSMRP) is presented. For the SSMRP, the term subsystem denotes those components and systems whose behavior during a seismic event may be determined to be decoupled from the major structural response. Typically, the mathematical model utilized for the major structural response will include only the mass effects of the subsystem and produce the support motions to be applied for subsystem seismic qualification. The goal of this project is to develop transfer functions to be used in the overall systems model. These transfer functions will relate the subsystem response to the input environment; i.e., the subsystem support motion. "Best estimate" methodology will be utilized to develop transfer functions for the overall systems model. These transfer functions will be dependent on a number of parameters such as the physical properties of the subsystem. The initial portion of this task deals with a definition of the state-of-the-art of seismic qualification methods for subsystems. To facilitate treatment of this broad class of subsystems, three classifications have been identified: multiply supported subsystems (e.g., piping systems); mechanical components (e.g., valves, pumps, control rod drives, hydraulic systems, etc.); and electrical components (e.g., electrical control panels). Descriptions of the available analysis and/or testing techniques for the above classifications are sought. The results of this assessment will be applied to the development of structural subsystem transfer functions.

● **7.4-22** Philip, G. and Bork, M., **KTA 2201—seismic design standards in the Federal Republic of Germany,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 2/7, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

To ensure a uniform and high level of safety for all nuclear power plants in the Federal Republic of Germany in the event of an earthquake, the Nuclear Safety Standards Commission (KTA) commenced work on a six-part nuclear safety standard, KTA 2201, "Design of Nuclear Power Plants against Seismic Events." This paper examines Part 2—Characteristics of Seismic Events and Part 3—Design of Structural Components, for which substantial progress has been made in recent months. Part 2 deals in detail with seismic and soil input parameters, and presents requirements for defining the design and safety earthquakes at a site. The basic parameter used in defining the seismic event is the macroseismic intensity. The standard will prescribe a method for obtaining a reasonable relationship between the design and safety earthquakes. The design earthquake is first determined, and then the safety earthquake, which is usually about one intensity larger, is derived. The maximum horizontal acceleration for the site is then determined using a fixed-intensity–acceleration correlation. For the standard design response spectrum (the response spectrum method is one of the methods suggested), a modified version of the U.S. Nuclear Regulatory Commission spectrum is used. Part 3 presents the requirements for the detailed design of structural components. These requirements include the analytical methods to be used, the damping factors without consideration of stress levels, and the permissible stresses for concrete, steel, and masonry.

● *See **Preface**, page v, for availability of publications marked with dot.*

● **7.4-23** Shibata, H. and Okamura, H., **On a method of evaluation of failure rate of equipment and pipings under excess-earthquake loadings,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 2/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper deals with a method for evaluating the failure rate of equipment and piping systems in nuclear power plants when subjected to an earthquake that exceeds the design basis earthquake. If the ratio of the maximum ground acceleration of an earthqake to that of the design basis earthquake is n, then the failure rate or the probability of failure is the function of n, or $p(n)$. The purpose of this study is to establish a procedure for evaluation of the relationship between n and $p(n)$.

● **7.4-24** Gupta, D. C., Agrawal, P. K. and Singh, S., **Input criterion for seismic analysis of nuclear power plants,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 1/6, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper presents the results of a study made to assess the conservatism of applying the U.S. Nuclear Regulatory Commission Regulatory Guide (R.G.) 1.60 spectrum at the foundation elevation in the free field. Two types of soil sites are investigated: (1) a stiff soil site and (2) a deep cohesionless soil site. Several appropriate earthquake motions recorded at sites representative of the types of sites used in this study are used. The acceleration time histories of the recorded earthquake motions, scaled to the same peak acceleration (A_{max} 0.1g), are applied at the surface and the resulting motions are obtained at various elevations in the free field. For each case, the soil properties are varied within a practical range (±50%). The resulting motions at various elevations are compared with the results obtained at the same elevations using the R.G. 1.60 spectrum for maximum ground acceleration equal to 0.1 g and applied at the foundation elevation. The results of the study show that the foundation level definition of the R.G. 1.60 spectrum is more conservative than the case in which the seismic input motion is applied at the ground surface. It is concluded that a reasonable set of soil properties is sufficient for an analysis using the foundation level definition of the R.G. 1.60 spectrum; because of the inherent conservatism of the definition, it is not necessary to consider the variation of soil properties.

● **7.4-25** Rieck, P. J., **Integrated structural design of nuclear power plants for high seismic areas,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 4/2, 7. (For a full bibliographic citation, see Abstract No. 1.2-20.)

A design approach that structurally interconnects nuclear power plant buildings to be located in high seismic areas is described. The design evolution as the plant is structurally upgraded for higher seismic requirements is described for a typical 600 MWe steel cylindrical containment PWR. The original plant layout is maintained throughout. The plant design is presented as having a separate reactor building and auxiliary structures for a low seismic area (0.20 g) and is structurally combined at the foundation for location in a higher seismic area (0.30 g). The evolution is completed by a fully integrated design which structurally connects the reactor building and auxiliary structures at superstructure elevations as well as at foundation levels for locations in very high seismic risk areas (0.50 g). To demonstrate the effects of the differences in the designs, each of the three structural configurations is seismically analyzed and the seismic responses are compared. Each configuration assumes the same site soil conditions (uniform dense soil, with an average shear modulus of about 5000 kg/cm^2) and is subjected to the same earthquake ground motion (SSE, peak acceleration of 0.50 g).

The unique feature of the fully integrated design is the structural connection of the shield building with the surrounding auxiliary structure at the superstructure elevations, whereas previous designs utilize a "rattle space" between the two structures to allow for the differences in vibrational response during an earthquake. In the integrated design, all structural members contribute to the overall strength and stability of the plant. The elimination of independent seismic motion and the achieving of a more uniform seismic response facilitates equipment qualification and mechanical design. By allowing shield building loads to be transferred into the auxiliary structures, reinforcement congestion in the lower portions of the shield building surrounding penetrations can be reduced.

● **7.4-26** Asmis, G. J. K. and Atchison, R. J., **The MCE (maximum credible earthquake)—an approach to reduction of seismic risk,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 2/8, 9. (For a full bibliographic citation, see Abstract No. 1.2-20.)

It is the responsibility of nuclear regulatory bodies to ensure that radiological risks resulting from the effects of earthquakes on nuclear facilities do not exceed acceptable levels. In simplified numerical terms, this means that the frequency of an unacceptable radiation level must be kept below 10^{-6} per annum. Unfortunately, seismic events fall into the class of external events which are not well defined at these low-frequency levels. Thus, design earthquakes have been chosen, at the 10^{-3}-10^{-4} frequency level, a level commensurate with the limits of statistical data. There exists, therefore, a need to define an additional level of earthquake. A seismic design explicitly and implicitly

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

recognizes three levels of earthquake loading: one comfortably below yield, one at or about yield, and one at ultimate. The ultimate level earthquake, contrary to the first two, has been implicitly addressed by designers by choosing systems, materials, and details compatible with postulated dynamic forces. It is the purpose of this paper to discuss the regulatory specifications required to quantify this third level, or maximum credible earthquake (MCE).

The intensity and duration of the radiological exposure following an earthquake is a function of the following three elements: (1) the severity of the earthquake; (2) the resistance offered by the engineered structures and equipment to the seismic event; and (3) the release and dispersion of the radiological effluent to members of the public if the resistance is insufficient. With the present incomplete knowledge of tectonic processes in eastern Canada, there is no alternative but to extrapolate, on the basis of the best available scientific evidence, to the low-frequency events required. This extrapolation has been carried out using a Monte Carlo simulation technique. The result is an ensemble of earthquakes catalogued as to near- and far-field events. To these, representative time histories have been assigned. Such an exercise indicates the relative importance of near and far events and shows, for example, that for eastern Canada, the random, background earthquake occurring close to a plant would cause the major seismic threat. A nuclear power plant must be built to survive the effects of the ensemble of earthquakes defined in element (1). The use of design in the inelastic range is explored by the use of coupled, two degree-of-freedom models, employing softening (hysteretic) and hardening (gap-impact) restoring functions. A "matrix" approach is employed to investigate, in a systematic manner, the nonlinear effects of equipment only, structure only, and structure and equipment. It is shown that, except for certain anomalies such as nonlinear torsional coupling and internal resonance conditions, the use of nonlinear properties (provided that the design has incorporated the required ductility and continuity properties) will ensure the survival of passive structures and systems to the ensemble of earthquakes that specify the MCE. Finally, the third element is discussed and the consequences are placed into perspective with other risks caused by nuclear plant failures and with general societal risks.

● **7.4-27** Lazzeri, L., Agrone, M. and Strona, P. P., **Seismic design of cableways: a cad approach,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(b), Paper K 11/10, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

The problems associated with the seismic-resistant design of such light metallic structures as supports for cableway conduits are considered. The aim of the research is to provide the designer with the knowledge necessary to simplify his task and to outline the methods and tools necessary for the most straightforward and economical design of cableways, conduits, and their supports. The following methods and analyses were conducted. (1) The ASDIC structural static and dynamic analysis program was used in the analysis of stresses resulting from static and dynamic conditions and in an analysis for compliance with the American Society of Mechanical Engineers' 3 NF rules. (2) An analysis was performed of the maximum static and dynamic loads compatible with a given geometry. The change of eigenfrequencies and acceleration response caused by changing loads is considered by means of an iterative procedure, which is described in detail. A preprocessor subroutine has been added in order to make use of the program easy and to minimize computer time, at least for commonly used structures. About 100 geometrical configurations, ranging from a one cable-layer-type to a six cable-layer-type with different span lengths, have been considered. Three types of sections (heavy, medium, and light) are considered. A normalized set of drawings are given to minimize the designer's efforts. (3) A simplified spectrum representing the seismic input is defined. The spectrum represents an envelope of many floor response spectra and it is considered reasonable for unification purposes. (4) A qualification of the unified structures defined in (2) is performed by means of ASDIC; for each configuration for a section type, possible braces are given to make the section compatible with the spectrum defined in (3).

● **7.4-28** Shibata, H. and Kato, M., **On fundamental concept of anti-earthquake design of equipment and pipings,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 4/1, 8. (For a full bibliographic citation, see Abstract No. 1.2-20.)

This paper describes a new concept for the seismic-resistant design of equipment and piping systems in nuclear power plants. The usual seismic-resistant design for such systems begins with use of design basis ground motions calculated from floor responses and ends with a stress analysis of each structural element. However, the same type of equipment is used for plants with various site conditions. The commonly used method requires the repetition of such a design procedure with each plant. This new design method has been developed to avoid such time-consuming repetitions.

The method consists of a two-flow combination; one flow begins with use of the design basis ground motions and ends with the floor response spectrum, and the other flow begins with allowable limits, mostly allowable stresses, and ends with the allowable limit spectrum or the cricital floor response spectrum. This allowable limit spectrum or the critical floor response spectrum can be obtained by means of either design analysis or approval testing of each type of new system. These curves can also be considered to be fragility response curves. The method can be expanded

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

in three stages to take into account the critical limit force, the critical seismic coefficient, and the critical floor response curve. If a system is very rigid, then it might fail at some of its elements, such as at its legs, nozzles, etc., under the critical seismic load. In this case, it is possible to calculate the reaction forces at every leg, nozzle, and at other connecting elements. This might be called the "critical limit force," and this load can be expressed by the critical external force vector. A seismic coefficient, which gives the severest external force vector, can be defined as a "critical seismic coefficient." If a system is not rigid and is in a resonating region, the exciting floor motions should be lower than those in other frequency regions. This creates a notch on the uniform critical floor response curve which has a constant value equal to the seismic coefficient. Although such a critical floor response curve is constant and equal to the critical seismic coefficient, the curve has several notches at the frequencies corresponding to the eigenfrequencies of the system. This is the " critical floor response curve." These three critical values have corresponding allowable limit values for use in design.

The advantage of these methods is that one computation or testing is enough to determine such criteria. For a new plant, it is only necessary to calculate the floor responses at each level of the building and to compare the allowable limit values with these results. A large amount of the stress analysis of equipment and piping systems of a new plant could thus be eliminated. The three methods should be selected in accordance with the dynamic characteristics of the system under study.

● 7.4-29 Kana, D. D. and LeBlanc, R. W., **An evaluation of seismic qualification tests for nuclear power plant equipment**, *NUREG/CR-0345*, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C., Sept. 1979, 83.

A series of seismic qualification tests has been conducted on a typical nuclear power plant electrical cabinet. Acceleration and strain responses were measured for four ground level and six floor level specifications. The test types include resonance search, biaxial independent random, biaxial dependent random, uniaxial random, sine beat, and sine dwell excitations. Tests involving random motion were derived both from a random generator and earthquake signal source. Response data are initially presented in terms of transfer functions, time histories, and response spectra. Then, analytical parameters are developed for correlation of the data in terms of peak responses, time-averaged RMS responses, and a new parameter defined as a damage severity factor. Typical sine dwell and sine beat tests are found to be far more severe than biaxial random simulations. The developed damage severity factors indicate this result vividly and also provide a useful design tool for comparison of test severities before the tests are conducted so that a choice can be made.

● 7.4-30 U.S. Nuclear Regulatory Commission, **Reactor site criteria, 1975-1977**, *Rules and Regulations, 10 CFR, pt. 100*, Washington, D.C., 1978, 6. (With: U.S. Nuclear Regulatory Commission Regulatory Guide 1.29, rev. 3, Sept. 1978.)

● 7.4-31 Lin, C. W. and Pandya, J. M., **Applications of multi-directional seismic inputs in the design of components**, *Nuclear Engineering and Design*, 52, *1*, Mar. 1979, 127-133.

A method is presented to convert the existing component qualification level (gravitational acceleration) for two-directional earthquake input into an equivalent qualification level for three-directional earthquake input, and vice versa. This exact and conservative method is applicable to all simple equipment which uses static acceleration as the basis for design, such as auxiliary pumps, valves, tanks, heat exchangers, filters, and demineralizers.

● 7.4-32 Reddy, D. P., **Assessment of seismic analysis procedures for LMFBR in-core components**, rev. ed., *SAN-1011-118R*, Div. of Reactor Research and Technology, U.S. Dept. of Energy, Washington, D.C., Mar. 1979, 63.

This report provides an assessment of state-of-the-art dynamic seismic analysis procedures for in-core components of liquid metal fast breeder reactors. It is based upon a review of United States and foreign literature and upon discussions with technical personnel presently engaged in performing seismic design analyses of reactor in-core components.

The investigation reveals that one- and two-dimensional analyses are being used with uncoupled horizontal and vertical input motions being applied to separate mathematical models. Nonlinear response resulting from the impact of elements within an assembly is being represented with gapped springs and the energy loss is being represented by a viscous damping mechanism based on assumed coefficients of restitution. Fluid-structure interaction effects, impact between different fuel assemblies, and the effect of coulomb friction on the load pads are not generally being considered. A review of commercially available computer codes indicates that it is not economically feasible to perform complete three-dimensional analyses of in-core components with current software and hardware technology. A more sophisticated computer code (SCRAP) capability has been demonstrated and is under development at the Argonne National Lab. which can consider all the important phenomena governing the seismic response of the in-core components.

The report recommends that the development and documentation of the SCRAP computer program be accelerated so that it can be made generally available. The analysis procedure should consider three components of input motion simultaneously since the traditional approach which uses three separate models and superposition of the results is not valid for nonlinear behavior. Experimental determination of the effects of frictional forces and fluid drag forces on the in-core components is also recommended.

● 7.4-33 Masri, S. F., **Evaluation of seismic analysis techniques for LMFBR piping and equipment,** *SAN-1011-116,* Div. of Reactor Research and Technology, U.S. Dept. of Energy, Washington, D.C., 1978, 182.

The development of efficient and reliable methods for calculating the seismic forces on piping and equipment critical to nuclear power plant safety has been the subject of numerous studies. In an effort to evaluate the procedures currently used for deriving piping and equipment design spectra, this report (a) discusses considerations that arise in the seismic-resistant design of equipment-structure systems, such as characterization of earthquake inputs and modeling of equipment-structure systems; (b) assesses calculation techniques of in-structure response spectra; (c) evaluates a currently used approximate seismic analysis method; and (d) presents an "exact" probabilistic analysis of a coupled equipment-structure system under earthquake-like excitation. The study concludes that, of the three methods evaluated and compared for accuracy, feasibility, and confidence level of conservatism in the results of the analysis, the probabilistic approach is the most rational, the time history method is the next, and the "direct" methods are the least rational. Additional work is required to reduce the probabilistic method to a simple, practical design procedure.

7.5 Design and Construction of Miscellaneous Structures

● 7.5-1 Arze-Loyer, E., **Seismic design of industrial structures in Chile,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1307-1341.

Seismic design practices for industrial structures developed in Chile since 1945 are described in this paper. A summary of research, specifications, and design methods for the most common structures found in industrial projects is presented. The problems of project coordination between foreign and local engineers for adequate seismic analysis is analyzed. Consideration is also given to indirect and shutdown losses after a major earthquake, losses that are often far more important than direct structural losses.

● 7.5-2 Bureau, G. J., **Criteria for seismic analysis of large dams** (Criteres d'analyse sismique des grands barrages, in French), *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 1, 1979, 147-176.

A brief examination of the effects of past earthquakes on existing dams confirms the contention that seismic loading should be considered in the design of dams. At present, the methods of seismic analysis vary from one organization or design office to another. It is proposed that three loading levels be used for seismic analysis of dams using the finite element method: an operating basis earthquake, a design basis earthquake, and loading from induced seismicity. The procedure for selecting the seismic input is described in detail and illustrated by a typical example. The excitation time histories thus obtained are compatible with design response spectra that depend on the geological conditions at the dam site.

● 7.5-3 Schiff, A. J., Torres-Cabrejos, R. E. and Yao, J. T. P., **Evaluating the seismic reliability of electrical equipment containing ceramic structural members,** *Earthquake Engineering & Structural Dynamics,* 7, *1,* Jan.-Feb. 1979, 85-98.

A method is presented for evaluating the reliability of ceramic structural members subjected to earthquake-induced vibrations. The method uses the Weibull distribution to represent the probability of failure of the brittle ceramic material and includes the effects of stress concentrations introduced by flaws and the volume of material subjected to stress. The stress concentration introduced by the complex form of insulators and at the mounting interfaces is considered. A numerical example is given to illustrate the application of the method.

● 7.5-4 Esteva, L., **Seismic design of appendages under uncertainty,** *Engineering Design for Earthquake Environments,* Paper No. C198/78, 227-234. (For a full bibliographic citation, see Abstract No. 1.2-2.)

Uncertainties associated with earthquake intensities, characteristics of earthquake ground motions, and structural properties have a significant bearing on seismic-resistant design decisions. In the design of light equipment and appendages, the problem of uncertainties is accentuated because, under seismic excitations, such equipment is exceptionally sensitive to the properties of structures and structural members. This paper presents an optimization method for estimating the uncertainties mentioned above. For the optimum design of a deterministic model, it is found that the model responds in a far less sensitive manner to the natural periods of the appendage and the main structure than would be the case when designing for a target response. However, for a probabilistic model, it is found that the model responds in a far less sensitive manner to uncertainties than would be the case when designing for a fixed reliability. Guidelines are presented for the optimum design of appendages and light equipment idealized as having a single degree-of-freedom.

● 7.5-5 Cane, R. J., **The effects of earthquake loads on the design of pressure vessel shells,** *Engineering Design for Earthquake Environments,* Paper No. C169/78, 1-10. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The development of earthquake-induced forces and moments, which are transmitted to pressure vessel shells through their supports and through the piping systems to which the supports are connected, are shown through a design sequence that is not ideal. Nevertheless, unacceptably high stresses can be avoided by providing a plastic hinge to limit support reactions and by increasing reinforcement at nozzle connections. Some guidelines are presented for designing these stress-limiting features.

● 7.5-6 Hadjian, A. H., **Support motions for mechanical components during earthquakes,** *Engineering Design for Earthquake Environments,* Paper No. C173/78, 27-45. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The state-of-the-art methods used for prescribing support motions to equipment in structures are reviewed. Also discussed are the justifications for the uncoupling of the equipment from the structure for purposes of analysis and the impacts that uncertainties in the total process may have on equipment design.

● 7.5-7 Dungar, R. and Severn, R. T., **The aseismic design of structures and their foundations, including structure-fluid interaction,** *Engineering Design for Earthquake Environments,* Paper No. C180/78, 101-110. (For a full bibliographic citation, see Abstract No. 1.2-2.)

Offshore gravity platforms and different types of dams are used to illustrate available methods for the seismic-resistant design of fluid-foundation-structure systems. A frequency domain analysis is described for platforms which incorporates energy-absorbing boundaries. For dealing with added-mass effects, a fluid-structure coupling procedure is given in some detail. The paper concludes with sections on observed structural behavior in earthquakes, structural testing and site investigation, and the use of models.

● 7.5-8 Vint, J. V., **Protecting a turbo-generator installation against earthquakes,** *Engineering Design for Earthquake Environments,* Paper No. C182/78, 119-127. (For a full bibliographic citation, see Abstract No. 1.2-2.)

The paper describes the re-design of a turbogenerator installation in order to comply with a New Zealand earthquake specification. The major item in the plant is the turbogenerator, which stands on a steel table; a smaller steel table supports the boiler feed pumps. Design specifications for the supports are evolved and converted into designs that protect the plant against excessive seismic acceleration and displacement. A vibration damping system was developed for the steam and water piping for the same purpose. The paper concludes with recommendations for earthquake specifications.

● 7.5-9 Skjei, R. E., Chakravartula, B. C. and Yanev, P. I., **Seismic resistance of equipment and building service systems: review of earthquake damage, design requirements, and research applications in the USA,** *Engineering Design for Earthquake Environments,* Paper No. C189/78, 185-192. (For a full bibliographic citation, see Abstract No. 1.2-2.)

Recent major earthquakes have caused repetitive damage to certain building service system elements and to equipment. Modifications in building codes are being made to alleviate this increasingly serious problem. Nuclear power plant design studies provide an advanced technology for unusually critical facilities.

● 7.5-10 Bea, R. G., **Earthquake and wave design criteria for offshore platforms,** *Journal of the Structural Division, ASCE,* **105,** *ST2,* Proc. Paper 14387, Feb. 1979, 401-419.

A method that applies experience, projections of environmental conditions, response analyses, and reliability logic is used to develop earthquake and wave design criteria for one class of an offshore platform system. The system consists of a steel, tubular-membered, template-type superstructure supported on piles and firm soils in 300 ft of water. Three fictitious sites are considered: the eastern Gulf of Alaska, southern California, and the Santa Barbara Channel. Ranges of design wave heights and ground motion velocities are given. Results are compared with those appropriate for a conventional building structure and with those from API RP 2A guidelines for fixed offshore platforms. Good agreement with API guidelines is indicated.

● 7.5-11 Matsushita, H. and Sato, M., **The Hayahi-No-Mine prestressed bridge,** *Journal of the Prestressed Concrete Institute,* **24,** *2,* Mar.-Apr. 1979, 90-109.

This paper describes the design considerations (including one-fifth scale static and dynamic model tests) and construction techniques used to build the 50-m (164-ft) span Hayahi-No-Mine Bridge on the island of Kyushu in southern Japan. This unique single-span prestressed concrete structure combines characteristics of suspension, cable-stay, and ribbon bridge design.

● 7.5-12 Matsuo, M. and Horiuchi, T., **Earthquake damage and methodology of design of small diameter pipelines,** *Soils and Foundations,* **19,** *1,* Mar. 1979, 23-38.

Earthquake damage to underground pipelines is common. This paper proposes a decision method for determining the optimum kind of pipe (i.e., the optimum material for the pipe) for withstanding earthquake damage by using reliability theory. This paper describes the actual conditions of earthquake damage to pipelines and the results of the factorial analysis in relation to the type and state of the ground and the materials of pipes forming a pipeline. It is shown that earthquake damage to pipelines is strongly influenced by the *N*-value of the surface layer up to 5 m in depth and the kind of pipe. The probability of pipeline failure is calculated by using past data for actual damage; the decision method to determine the optimum kind of pipe is discussed, and numerical examples are given.

● **7.5-13** Grant, A., **The Pasco-Kennewick Intercity Bridge,** *Journal of the Prestressed Concrete Institute,* **24,** *3,* May–June 1979, 90–109.

The planning, design considerations, quality control program, and construction techniques involved in building the 2503-ft (763-m) long Intercity Bridge are described. This structure, which crosses the Columbia River in Washington State and connects the cities of Pasco and Kennewick, is the largest precast prestressed cable-stayed bridge in North America.

● **7.5-14** Housner, G. W. and Scott, R. F., **Earthquake considerations in dam design,** *International Water Power & Dam Construction,* 31, *7,* July 1979, 31–37.

Although few dams have been subjected to strong ground motion from earthquakes, and, consequently, the number of failures or partial failures has not been large, many dams will probably be constructed in seismic zones in the future because of the scarcity of other suitable sites. The potential seismic hazard is therefore high. The nature of earthquakes and strong ground movements is briefly discussed with respect to their influence on dam design and analysis.

● **7.5-15** Arya, S. C., O'Neill, M. W. and Pincus, G., **Design of structures and foundations for vibrating machines,** Gulf Publishing Co., Houston, 1979, 191.

The design of structures and foundations supporting dynamic loads has gradually evolved from an approximate rule-of-thumb procedure to a scientifically sound engineering procedure. Current state-of-the-art allows engineers to reliably design structures which support increasingly heavier and larger machines. Recent advances in a number of engineering disciplines, when merged with a traditional well-established body of theoretical knowledge, have resulted in definite procedures for the analysis and design of dynamically loaded structures. However, most concepts and procedures used in the design of structures carrying dynamic machines and ultimately supported by the soil have heretofore been dispersed in texts dealing with a single aspect or a limited portion of the problem. This text brings together all those concepts and procedures. Disciplines involved in modern design procedures include: theory of vibrations, geotechnical engineering including soil dynamics and half-space theory, computer coding and applications, and structural analysis and design. It is assumed that the reader is an engineer or designer who is familiar with these areas, but a basic introduction to each area is included to enhance the background of some readers.

Topics covered in the book include: alternatives of modeling dynamically loaded systems, the information necessary for design, the geotechnical aspects of the problem, flexible mats and deep foundations, and actual examples of different types of structures supporting dynamic machines.

● **7.5-16** Hempel, H. W., **Lateral loads on power boilers,** *Journal of the Energy Division, ASCE,* **105,** *EY2,* Proc. Paper 14751, Aug. 1979, 241–250.

The structural section of power-boiler specifications should include lateral-force design criteria to minimize the possibility of critical damage and resulting financial loss during a furnace explosion. Boilers designed for 20% g have survived violent explosions with moderate structural damage. In areas of low seismicity, reasonable protection can be attained by following specifications requiring minimum lateral design forces of 10% g and redundant bracing systems with strong and ductile connections that will bend and not rupture under out-of-plane loading.

● **7.5-17** Borovoi, A. A. and Michailov, L. P., **60 years of Soviet hydropower,** *International Water Power & Dam Construction,* **31,** *3,* Mar. 1979, 21–29.

This paper describes the hydroelectric industry in the U.S.S.R. Methods used for constructing several dams located in seismic areas are discussed, along with a brief description of site geology.

7.5-18 Bakht, B., Csagoly, P. F. and Jaeger, L. G., **Effect of computers on economy of bridge design,** *Canadian Journal of Civil Engineering,* **6,** *3,* Sept. 1979, 432–446.

This paper examines highway bridge costs in relation to the costs of an overall highway system, divides the bridge costs into various categories, and examines the feasibility of reducing the costs in these various categories by adopting computer-based methods of design. It is concluded that appreciable savings can be made in the construction costs, and that these savings greatly outweigh any possible increase in design costs needed to bring them about. The paper also considers the effect of computer-based design on the safety margins of the resulting bridges, and briefly examines the roles of the engineering profession and the drafters of code specifications in influencing designers to adopt computer-based methods. An appendix lists the programs commercially available in Canada for conducting static and dynamic analyses of highway bridges.

● **7.5-19** Gurpinar, A. and Erdik, M., **Seismic risk assessment of the mass transportation system of Ankara** (Ankara *toplu rayli tasin projesi sismik risk degerlendirmesi, in* Turkish), *Report 79-02,* Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, June 1979, 36.

The mass transportation system of Ankara is to be a railway system constructed partly underground. The two seismic sources constituting a potential threat to the system are the North Anatolian fault, 100 km north of Ankara, and the Kirsehir fault, 80 km east of Ankara. A small magnitude event ($M<5.5$) may also be expected to occur at the site. This report contains a seismic risk analysis for the site in terms of site intensity. The analysis is conducted using both probabilistic and deterministic methods. The major part of the report concerns the recommendations of an earthquake-resistant design approach for this structure. It is pointed out that displacements are the most important quantities determining the design, and that the system is more vulnerable to surface waves originating in either the North Anatolian or the Kirsehir fault zones.

● **7.5-20** Shibata, H., Shigeta, T. and Sone, A., **New types of ground motions for the anti-earthquake design of non-building industrial facilities,** *Bulletin of Earthquake Resistant Structure Research Center,* **12,** Mar. 1979, 25-41.

Based on the authors' own observations of ground motions and the seismic responses of the models of a tower, piping systems, vessels, and storage facilities, the characteristics of ground displacement in a range from 2 to 10 sec, torsional ground velocity in the vertical axis, and a wide range of ground acceleration motions are presented. The importance of these characteristics on the seismic-resistant design of industrial buildings is also discussed.

● **7.5-21** Bea, R. G. and Akky, M. R., **Seismic, oceanographic, and reliability considerations in offshore platform design,** *Proceedings of Eleventh Annual Offshore Technology Conference—1979,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3616, 1979, 2251-2262.

Decisions on the earthquake ground motions appropriate for design should include consideration of the structural design process and the projected performance of structures designed by such a process. Seismic design conditions depend not only on geology and seismology, but also on the characteristics of the structure to be designed and the degree of reliability desirable. Seismic exposure results from a recently completed study of Alaskan Continental Shelf areas are combined with results of a previous study of the performance and reliability characteristics of steel, tubular-membered, template-type, pile-supported offshore platforms. Effective ground accelerations applicable to API's normalized response spectra for design of offshore platforms are developed for two general locations: the eastern Gulf of Alaska and Lower Cook Inlet. These preliminary results indicate that substantial reductions in effective ground accelerations may be justified for Lower Cook Inlet. Current API values appear to be appropriate for the eastern Gulf of Alaska area.

7.5-22 Dunham, V. R. and Chalasani, R. M., **Copper refinery tankhouse, northern Canada: design and construction features,** *The Structural Engineer,* **57A,** *8,* Aug. 1979, 247-253.

● **7.5-23** Uchiyama, T. and Dobashi, Y., **Structural design of folded plate- and helicoidal shell-type of staircases (Part 2: free standing staircases U-shaped in plan view)** (in Japanese), *Transactions of the Architectural Institute of Japan, 284,* Oct. 1979, 29-39.

Part 1 of this report compared results of the analysis of three types of staircases with experimental results as part of a study on the structural design of reinforced concrete staircases composed of either a set of slabs or a helicoidal shell. With regard to free-standing staircases, it was confirmed that the ratio of the elastic limit to the ultimate strength of the structures decreases with an increased angle between the horizontal projections of the inner edges of the pair of flights of a staircase. In this paper, the angle is considered to be null while the horizontal distance between the two flights of the staircase, which are parallel in plan, is varied. Elastic and vibration analyses of the structure are conducted using the finite element method to clarify major characteristics of its static and dynamic behavior. These results are used in proposing approximate design formulas for this type of staircase.

● **7.5-24** Baba, S., **Extreme value design of reinforced concrete structure using worst-state extreme distribution** (in Japanese), *Transactions of the Architectural Institute of Japan, 285,* Nov. 1979, 63-70.

The concept of maximum mean largest value introduced by Gumbel is applied to the design of reinforced concrete structures and is named the worst-state design and/or extreme value design. The characteristics of the worst-state design are as follows: (1) The structure is designed by using minimum material strength and maximum external force. (2) Minimum material strength and maximum external force are derived as the minimum mean smallest value and the maximum mean largest value, respectively, by using the Lagrange multiplier method under the condition that the failure probability of the designed structure never exceeds a certain value. (3) Material strength consists of two independent parameters such as a steel rod and concrete. External force consists of two

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

independent parameters such as traffic load and earthquake load.

In this paper, the maximum mean largest value is first derived by introducing new characteristics *A, B, C* and *D* in order to reduce the excessive estimation of the largest value; second, the concept is extended to the estimation of the upper bound value of failure probability; third, the concept is also extended to the two-parameter problem, where two kinds of material strength and/or two kinds of external force are included; fourth, an example design of a reinforced concrete girder bridge is provided; and fifth, some execution error problems such as the location error of the steel rod of a reinforced concrete girder are discussed.

● **7.5-25** Godden, W. G., Imbsen, R. A. and Penzien, J., **An investigation of the effectiveness of existing bridge design methodology in providing adequate structural resistance to seismic disturbances; phase VII summary,** *FHWA-RD-79-90*, Federal Highway Admin., U.S. Dept. of Transportation, Washington, D.C., Dec. 1978, 48.

This summary report is the last in a series compiled from the investigation, "An Investigation of the Effectiveness of Existing Bridge Design Methodology in Providing Adequate Structural Resistance to Seismic Disturbances," sponsored by the U.S. Dept. of Transportation, Federal Highway Admin. This report presents brief summaries of the reports listed below. It also presents general design and research recommendations for highway bridges based on the knowledge and experiences gained during this seven-year investigation. (1) A thorough review of the world's literature on seismic effects on highway bridge structures including damages to bridges during the San Fernando earthquake of Feb. 9, 1971. (2) An analytical investigation of the dynamic response of long, multiple-span, highway overcrossings. (3) An analytical investigation of the dynamic response of short, single, and multiple-span highway overcrossings. (4) Detailed model experiments on a shaking table to provide dynamic response data similar to prototype behavior which can be used to verify the validity of theoretical response predictions. (5) Correlation of dynamic response data obtained from shaking table experiments with theoretical response and modification of analytical procedures as found necessary. (6) Analytical investigation of the seismic response of bridges conducted in case studies to evaluate and make recommendations pertinent to current seismic design provisions and methodology.

● **7.5-26** Prendergast, J. D., **Probabilistic concept for gravity dam analysis,** *Special Report M-265*, Construction Engineering Research Lab., U.S. Army Corps of Engineers, Champaign, Illinois, Aug. 1979, 68.

This report describes a probabilistic concept for evaluating the safety of concrete gravity dams against sliding and overturning failures; the evaluation is conducted in terms of the various sources of uncertainty underlying the design parameters. This concept is used to compute the probability of sliding and overturning failures of two moderately low non-overflow gravity dams designed using conventional design procedures for reservoir water loadings, and, in one instance, earthquake loadings. The results show that it is possible to quantify the safety of a dam in a probabilistic sense.

● **7.5-27** Barbat, H., **The seismic analysis of elevated water tanks considering the interaction phenomena,** Structural Mechanics Dept., Polytechnic Inst. of Iasi, Romania, 1978, 67.

The report concerns the seismic design of elevated water tanks, taking into account fluid-structure and soil-foundation-structure interaction. Deterministic and stochastic analysis methods are developed in the report. The conclusions are based on the theoretical research, on numerical results obtained by using computer programs, on experimental results, and on the observations made concerning the behavior of elevated water tanks during the Mar. 4, 1977, Romanian earthquake.

● **7.5-28** Shaoping, S., **Earthquake damage to pipelines,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 23-38. (Additional papers bound separately in second half of "Special Session on Earthquake Engineering in China [papers].")

Several major earthquakes occurring in the People's Republic of China in recent years have caused severe damage to pipelines transporting industrial water, domestic water, municipal sewage, and gas. This paper briefly describes and compares damage caused by the Haichen earthquake of Feb. 4, 1975 (M = 7.3), and the Tangshan earthquake of July 28, 1976 (M = 7.8). Results of tests conducted on pipeline joints are presented.

● **7.5-29** Degenkolb, O. H., **Strengthening existing bridges to increase their seismic resistance,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. II, Paper No. 66, 15.

As a result of the Feb. 1971 San Fernando earthquake in California, it was learned that many of the bridges built prior to 1971 had seismic deficiencies. In addition to revising design specifications and detailing practices, the California Dept. of Transportation has initiated a program to retrofit pre-1971 bridges to make them more earthquake resistant. The current programs consist of adding restrainers to hinges and bearings on 649 bridges at a cost of $22 million. The department is also studying methods for increasing the seismic resistance of bridge columns. This paper covers the design criteria for retrofitting bridge

● *See **Preface**, page v, for availability of publications marked with dot.*

hinges and bearings, details which have been used, and proposed details for increasing the seismic resistance of columns.

● 7.5-30 Wang, L. R.-L., **Some aspects of seismic resistant design of buried pipelines,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 117-131. (For a full bibliographic citation, see Abstract No. 1.2-16.)

This paper discusses aspects of the seismic-resistant design of buried pipelines and takes into account the observed behavior when subjected to ground shaking. The factors that control the seismic-resistant design of buried pipelines are the imposed pipe strains and relative joint displacements if the pipeline is segmented. The upper bounds of pipe strains and relative joint displacements caused by earthquakes are discussed.

A proposed quasi-static analysis model is used to study the effects of various physical, geotechnical, and seismological parameters on seismic-resistant designs. The physical parameters are the geometrical and mechanical pipe properties, including pipe diameter, thickness, segment length, Young's modulus, and joint spring resistance. The geotechnical parameters include the soil-structure interaction constant, its variation along the pipeline, and the wave propagation velocity. The seismological parameters include the wave form and duration and amplitude of the ground displacement time history. Results that lead to a better understanding of the seismic response have been obtained. Based on these seismic response characteristics, design criteria and further research are discussed.

● 7.5-31 Mohammadi, J. and Ang, A. H.-S., **Seismic safety analysis of lifeline systems,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 161-179. (For a full bibliographic citation, see Abstract No. 1.2-16.)

Methods for assessing the seismic safety of a lifeline system are developed and introduced. Two types of hazards from earthquakes are considered: a fault-rupture strike on one or more links of a lifeline system and damage caused by strong ground shaking during an earthquake. The methods are illustrated for a specific water distribution system in Tokyo.

● 7.5-32 Shinozuka, M. and Koike, T., **Estimation of structural strains in underground lifeline pipes,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 31-48. (For a full bibliographic citation, see Abstract No. 1.2-16.)

A risk analysis methodology previously developed for underground pipeline systems by one of the authors made use of a conversion factor β to estimate the structural strain in underground pipelines induced by propagating seismic waves. The purpose of this study is (1) to derive a practical procedure for estimating the conversion factor that can be used not only for straight and bent pipes but also for structural details with more complex geometry, and (2) to determine the conversion factor for a number of typical cases in order to provide analysts with numerical insight of its values consistent with the physical conditions to which the pipeline system is subjected.

● 7.5-33 Ariman, T. and Muleski, G. E., **A review of the response of buried pipelines under seismic excitations,** *Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation,* 1-29. (For a full bibliographic citation, see Abstract No. 1.2-16.)

In this paper, an updated and detailed review of the seismic response and seismic-resistant design of underground piping systems is presented. Since modern cities depend heavily on utility systems for their day-to-day operation, earthquake threats to utility systems become increasingly important in proportion to the level of urbanization. It is apparent that the seismic behavior of buried pipeline systems is quite different from that of above-ground structures.

● 7.5-34 Pagay, S. N. and Loceff, F., **Seismic design of long underground structures,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 7/4, 6. (For a full bibliographic citation, see Abstract No. 1.2-20.)

Portions of long underground tubular structures such as circulating water tunnels, piping systems, and reinforced concrete electrical cable ducts often underlay nuclear power plant facilities. Their cross sections may range from a few centimeters to a few meters, and they are usually constructed of steel or reinforced concrete. As a consequence, the relative stiffnesses of the structures with respect to the surrounding soil vary widely. Under earthquake conditions, these buried structures respond to various seismic waves propagating through the soil media. Also, the relative dynamic motions of the connecting structures further influence these buried structures. This paper studies underground reinforced concrete tunnels and similar structures and develops simplified seismic analysis and design procedures for these structures. The treatment presented in this paper is primarily design oriented. Various geometrical configurations and boundary conditions are possible. The effect of the soil is considered by use of soil springs. The embedment effect can also be appropriately included. Structural design criteria are developed, including consideration of active, dynamic, and passive soil pressures, thermal loads, and relative displacements of the tunnel ends. Design examples for use in a nuclear power plant facility show application of the criteria. It is concluded that the procedure presented yields a realistic, cost-effective design.

● **7.5-35** Krishnaswamy, N. R., Nair, P. G. B. and Kanderphole, B. N., **Computer applications in the design of machine foundations**, *International Conference on Computer Applications in Civil Engineering, October 23–25, 1979, Proceedings*, NEM Chand & Bros., Roorkee, India, 1979, VII-39–44.

Computer-oriented designs for the foundations of an impact-producing machine and a reciprocating engine are presented. The programs prepared are general and can accommodate any design data for the machines and the supporting soils. By successive corrections of the design parameters, the procedure provides a method for developing a dynamic response of the foundation which falls within safe design limits. The programs, written in FORTRAN IV, will not stop when the first safe design is reached but will generate other designs also, enabling one to arrive at the optimum economical design.

● **7.5-36** Bapat, V. A. and Prabhu, P., **Optimum design of Lanchester damper for a viscously damped single degree of freedom system by using minimum force transmissibility criterion**, *Journal of Sound and Vibration*, **67**, *1*, Nov. 8, 1979, 113–119.

The problem is investigated of the optimum design of a Lanchester damper for a viscously damped single degree-of-freedom system subjected to harmonic excitation. The criterion of minimum force transmissibility is used in the analysis. Explicit expressions are developed for determining the optimum absorber parameters. It is shown that for the particular case of the undamped single degree-of-freedom system the results reduce to the classical ones obtained by using the concept of a fixed point on the transmissibility curves.

● **7.5-37** Rao, S. S. and Singh, K., **Optimum design of laminates with natural frequency constraints**, *Journal of Sound and Vibration*, **67**, *1*, Nov. 8, 1979, 101–112.

A method for the optimal design of symmetric fiber-reinforced composite laminates subject to constraints on natural frequencies is presented. The problem is cast as a nonlinear mathematical programming problem in which the thicknesses of material placed at preassigned orientation angles are treated as the design variables. The resulting optimization problem is solved by using an interior penalty function algorithm. Several nonlinear programming problems are solved by taking minimization of weight or maximization of fundamental frequency/buckling load/maximum transverse deflection under the stated loading condition as the behavior constraints. The numerical results are presented in the form of design studies which reveal the influence of different design constraints on the optimum design. These design studies illustrate that the method presented offers an efficient and practical optimum design procedure for composite laminates.

● **7.5-38** Yee, A. A., **Record span box girder bridge connects Pacific Islands**, *Concrete International*, **1**, *6*, June 1979, 22–25.

A concrete box girder bridge incorporating the world's longest span, 790 ft, connects two of the Palau Islands, 700 miles southwest of Guam. Form travellers allowed simultaneous construction of both bridge halves (from the end abutment to the main pier and to the midspan of the main span). The Koror-Babelthuap Bridge is designed to resist 150 mph winds and Zone III earthquake intensities.

● **7.5-39** Lin, T. Y., Lu, H. K. and Redfield, C., **The design of the Ruck-A-Chucky bridge**, *Concrete International*, **1**, *7*, July 1979, 31–37.

This paper describes the proposed Ruck-A-Chucky bridge, a "hanging arc" bridge which will cross the American River in California. Having no center piers, this unique 1300-ft (396-m) curved bridge will be suspended by cables anchored to the canyon walls on both sides of the river. Details of the studies conducted and design criteria of this bridge are described.

● **7.5-40** Bridges, C. P., **Long-span continuous concrete girder bridge supported by cables**, *Concrete International*, **1**, *5*, May 1979, 42–50.

The longest cable-stayed bridge in North America spans Washington State's Columbia River, connecting the cities of Pasco and Kennewick. Built in an earthquake zone, this 2503-ft-long structure has a segmental deck made from precast, post-tensioned 300-ton segments. The deck is supported by steel cables over 1794 ft of the roadway's length. These cables are anchored atop two pair of 250-ft concrete towers and along the edges of the bridge every 27 ft.

● **7.5-41** **Federal dam safety report of the OSTP Independent Review Panel**, Executive Office of the President, U.S. Office of Science and Technology Policy, Washington, D.C., Dec. 6, 1978, 48.

This report includes the following chapters: I—Executive Summary; II—Basic Considerations in Dam Safety; III—Evaluation of Agency Practices; IV—Guidelines for Achieving Dam Safety; and V—Federal Role in Dam Safety. Included in three appendixes are Guidelines for Professional Development of Engineering in Government; Position Statement on Dam Inspection Program and Engineer's Liability; and Proposed Federal Dam Safety Office.

● **7.5-42** Gould, P. L., **Environmental loadings on concrete cooling towers—types, likelihood, effects and consequences**, *Engineering Structures*, 1, *5*, Oct. 1979, 258–263.

● *See **Preface**, page v, for availability of publications marked with dot.*

This paper discusses the major types of environmental loadings (thermal, wind, and seismic) that may act on tall cooling towers. The emphasis is directed towards those aspects which are important in the design of such structures. In each case, the present design representations of the various loading conditions are explored and, when possible, needs for more realistic representations are identified.

7.5-43 **A fully prefabricated elevator in an 8-point seismicity zone** (Polnosbornyi elevator v zone 8-ball'noi seismichnosti, in Russian), *Beton i zhelezobeton, 6,* June 1979, p. 1.

A description is given of a fully prefabricated grain elevator built in the Alma-Ata region. Grain elevators are usually built by cast-in-place methods. Some details of formwork and erection procedures are provided. The earthquake-resistant elevator is topped with a metal sandwich structure.

● **7.5-44** Gould, P. L., **Environmental loadings on concrete cooling towers–types, likelihood, effects and consequences,** *Environmental Forces on Engineering Structures,* 3-18. (For a full bibliographic citation, see Abstract No. 1.2-28.)

The objectives of this paper are (1) to describe some commonly encountered environmental loading conditions (thermal, wind and seismic) for which large cooling towers must be designed; (2) to examine the likelihood of each occurring; (3) to characterize the predominant structural effects; and (4) to point out some consequences for design.

● **7.5-45** Robinson, R. R., Longinow, A. and Chu, K. H., **Seismic retrofit measures for highway bridges–Volume 1: Earthquake and structural analysis; Volume 2: Design manual,** *FHWA-TS-79-216 & 217,* Federal Highway Admin., U.S. Dept. of Transportation, Washington, D.C., Apr. 1979, 2 vols., 202. (NTIS Accession Nos. PB 80 103 195 and PB 80 103 203)

The primary objectives of the report are to (1) provide current information on the theory and techniques for seismic analysis of highway bridges, including background material on basic structural dynamics; (2) identify the appropriate criteria necessary to decide if a bridge needs retrofitting and the type of retrofit measures to employ; and (3) demonstrate design details and installation specifications for retrofitting existing highway bridges to minimize earthquake damage. Volume 1 includes a definition of terms, seismic risk maps, techniques and equations for the analysis of existing bridges subject to earthquake loadings, and criteria for determining if a bridge warrants retrofitting.

7.5-46 Arya, S. C., Feng, E. G. and Pincus, G., **Optimum design of steel pipe racks,** *Engineering Journal, AISC,* **16,** *3,* 1979, 84-97.

This paper describes the use of the STRUDL II computer program for the optimum design of a steel pipe rack structure commonly used in petrochemical plants. The procedure leads to substantial weight (and cost) savings in most situations. When the tonnage of steel used in petrochemical plant pipe racks is considered, the savings potential may be remarkable.

● **7.5-47** Wang, L. R.-L., **Seismic analysis and design of buried pipelines,** *SVBDUPS Project Technical Report 10,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Aug. 1979, 12.

This paper describes seismic-resistant analysis procedures and design criteria for buried piping systems. The paper is based on the simplified analysis and quasi-static analysis approaches for analyzing the axial strains and relative joint displacements caused by seismic ground shaking. To fulfill the analysis requirements, the related parameters are discussed. Failure criteria and design considerations are recommended. This paper also presents some passive and active design considerations to reduce damage to buried pipelines from earthquakes.

7.6 Design and Construction of Foundations, Piles and Retaining Walls

● **7.6-1** Graff, E. D. and Zacher, E. G., **Sand to sandstone: foundation strengthening with chemical grout,** *Civil Engineering, ASCE,* **49,** *1,* Jan. 1979, 67-69.

This article discusses the case of a large school in California, founded on fine sand, which was in need of structural rehabilitation for earthquake resistance. The conventional approach would have been to underpin and pour larger footings. Instead, chemical grout was used to increase the bearing capacity of the soil at an estimated savings of $1 million.

● **7.6-2** Richards, Jr., R. and Elms, D. G., **Seismic behavior of gravity retaining walls,** *Journal of the Geotechnical Engineering Division, ASCE,* **105,** *GT4,* Proc. Paper 14496, Apr. 1979, 449-464.

This paper shows that in order to use the quasi-static Mononobe-Okabe analysis for the prediction of earthquake dynamic forces on a gravity retaining wall, wall inertia effects must be included. A design procedure is developed in which the designer chooses an acceptable level of wall displacement; he then computes the design wall weight which will restrict displacement in an earthquake to the

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

predetermined level. Wall inertia effects are shown to be of the same order as the dynamic soil thrust and to be sensitive to vertical acceleration and to base and wall friction. Design recommendations are given which relate to proposed United States provisions for seismic zoning.

● **7.6-3** Taylor, P. W. and Williams, R. L., **Foundations for capacity designed structures,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 85-106.

This paper examines the application of capacity design methods to foundations. Results of research on foundation rocking are reviewed and used to formulate a rational design procedure.

● **7.6-4** Elms, D. G. and Richards, R., **Seismic design of gravity retaining walls,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 281-299.

Using Mononobe-Okabe analysis, the authors investigate the seismic behavior of gravity retaining walls. The importance of including wall inertia effects is demonstrated. The sensitivity of the results to changes in various parameters is also explored. For a moderately severe earthquake, it is shown that most walls will move, but that the movement is finite and calculable. An approximate expression is given for the expected displacement. A design approach is then developed in which the designer chooses an allowable displacement, uses it to compute a design acceleration coefficient, and then computes the wall mass required.

● **7.6-5** Asama, T. et al., **Recent earthquake resistant design methods for different types of foundation in Japan,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 702-715.

In order to elucidate present earthquake-resistant design methods for bridge foundations used in Japan, 31 examples of long-span bridges are given. The foundations are classified into four types. For each type, the authors surveyed the design methods used and the methods of developing models for foundation-soil interaction. The current trend in earthquake-resistant design is to evaluate behavior during earthquakes. From a methodological standpoint, earthquake-resistant design calculation has now reached a state capable of making the evaluations required in designing earthquake-resistant structures.

● **7.6-6** Buch, A., **Pile behaviour in earthquakes,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 290-305. (For a full bibliographic citation, see Abstract No. 1.2-21.)

In this paper, an attempt has been made at comparing pile behavior during earthquakes with applicable codes at the time of the design and construction of the structures studied. The principal area of discord with the guidelines recommended in codes for pile behavior concerns errors in the fundamental assumptions in the codes which have subsequently been rectified in the proposed all-purpose code drafted by the Applied Technology Council (ATC-3). The first part of the paper deals with the assumptions in the codes and the reports of investigations carried out of post-earthquake damage to pile structures at Caracas (1967), Niigata (1964), and Alaska (1964). The second part presents some of the revisions in terms of pile structure design as recommended in ATC-3. The third part attempts to offer a step-by-step process for arriving at a rational design plan. References are given to literature dealing with each step of the design process.

● **7.6-7** Gerwick, Jr., B. C. and Brauner, H. A., **Design of high-performance prestressed concrete piles for dynamic loading,** *Behavior of Deep Foundations,* 323-334. (For a full bibliographic citation, see Abstract No. 1.2-23.)

Although prestressed concrete pilings have given exemplary performance as foundation piling and although there exists ample guidance for their design, manufacture, and installation for such purposes, recent extensions of their application to more demanding situations requires a renewed look at the criteria for longitudinal prestress (precompression) and spiral confinement. Problem areas include the occasional occurrence of transverse cracking under heavy driving into erratic soils, longitudinal cracking during and after installation, and the need for ductile response to imposed deformations due to earthquakes. A more rational analysis is presented to explain and quantify these phenomena and the stresses and strains developed. Recommendations are then made giving values of prestress and steel requirements that will enable these severe criteria to be met. Some of these recommendations are supported by tests that are as yet unreported elsewhere. It is believed that these recommendations will enhance the capabilities of prestressed concrete piling and thus make practicable their extension to more demanding applications.

7.7 Design and Construction of Soil and Rock Structures

● **7.7-1** Bartos, Jr., M. J., **101 uses for earth reinforcement,** *Civil Engineering, ASCE,* 49, *1,* Jan. 1979, 51-57.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

One earth-reinforcement concept which was used first only for vertical retaining structures is now used for sloping-faced retaining structures, embankment foundation slabs, dams, containment dikes, slide buttresses, and bridge abutments. Another technique, used first for underpinning, is now used to stabilize landslides. Still others are being developed for strengthening earth embankments without retaining structures, for constructing low-cost or expedient roadways, and for strengthening the soil beneath an existing wall or beneath one to be built. This overview of earth reinforcement is based on papers presented at a symposium on earth reinforcement held in Apr. 1978 at the ASCE National Convention.

● 7.7-2 Datta, M., **Design of the Beas dam embankment,** *International Water Power & Dam Construction,* 31, 6, June 1979, 58-63.

The earth dam of the Beas project was the first high earth dam to be designed and constructed in India. It is 132.6 m high, with a gravel shell, and impounds 8570 x $10^6 m^3$ of water. The powerhouse has an installed capacity of 240 Mw, with provision for two more 60 Mw units at a later stage. The dam site area is seismically active and is situated approximately 60 km from the epicenter of the 1905 Kangra earthquake. This article on the Beas project outlines the various factors which influenced the design of the dam, and compares the dam with two similar structures, the Ramganga in India and the Mangla in Pakistan.

● 7.7-3 Oner, M., Gurpinar, A. and Erdik, M., **A preliminary evaluation of design seismic coefficients for Ataturk rockfill dam,** *Report 79-03,* Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, June 1979, 25.

This report presents preliminary results of studies of earthquake response analyses of Ataturk Dam. The purpose of this study is to provide a preliminary, yet realistic and rational assessment of design seismic coefficients so that design studies may proceed while final results of the full dynamic analyses are not yet available.

● 7.7-4 Seed, H. B., **Considerations in the earthquake-resistant design of earth and rockfill dams,** *Géotechnique,* XXIX, 3, Sept. 1979, 213-263.

The factors to be considered in the earthquake-resistant design of dams are discussed and defensive measures which may be taken to mitigate the effects of these factors are summarized. Available information concerning the field performance of dams during earthquakes is reviewed and conclusions are drawn concerning the potential for earthquake-induced sliding for different types of construction materials and earthquake shaking intensities. Finally, available methods for evaluating the stability and deformations of the slopes of a dam as a result of earthquake shaking are reviewed and their applicability illustrated. Conclusions are drawn concerning the significance of the type of soil used for construction and the possibility of delayed failure, after the earthquake ground motions have stopped, caused by pore water pressure re-distribution within an embankment. Suggestions are made concerning the appropriate role of analytical procedures in the overall assessment of the seismic stability of dams in relation to the uncertainties involved in the analysis procedures.

● 7.7-5 Nandakumaran, P., **Earthquake resistant design of earth retaining structures,** *Proceedings of First Caribbean Conference on Earthquake Engineering,* 384-395. (For a full bibliographic citation, see Abstract No. 1.2-21.)

The seismic-resistant design of earth retaining structures is studied experimentally using large-scale models. Taken into account are the effect of the structural characteristics of the wall-foundation system and the characteristics of the ground motion or the dynamic earth pressure and its distribution. It is shown that the increase in earth pressures is correlated with peak ground velocities. On the basis of these experimental findings, a method is proposed to obtain values of earth pressure distribution for design purposes.

● 7.7-6 Bolognesi, A. J. L., **Peculiarities of the seismic resistant analysis of earth dams with pervious gravelly shells** (Peculiaridades del calculo sismoresistente de las presas con espaldones permeables de grava, in Spanish), *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 35-47. (For a full bibliographic citation, see Abstract No. 1.2-22.)

● See ***Preface,*** *page v, for availability of publications marked with dot.*

8. Earthquake Effects

8.1 General

● **8.1-1** Del Tosto, R., **A probabilistic seismic damage model,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 773–782.

In this study, a damage-statistics approach is used to develop structural damage probabilities and to incorporate the uncertainty of the estimates that results from the limited data processed. Although no assumption is made of structural system behavior, direct correlations are obtained between strong ground motion parameters and damage.

● **8.1-2** Liu, B.-C. and Hsieh, C.-T., **Earthquake risk and damage estimates for New Madrid,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 763–772.

Data are presented to contribute to a better understanding of the earthquake risk and the social and economic effects of possible damaging earthquakes in the New Madrid damage zone, including the St. Louis and Memphis Standard Metropolitan Statistical Areas and two rural counties, Cape Girardeau and New Madrid. A model, integrating earthquake risk predictions and potential risk populations, is developed. To provide statistical estimates of the damage to various types of populations, given the intensity and probabilities of earthquake risk, ground conditions, and susceptibility to earthquakes, a number of physical and economic damage functions are derived. Presented are results produced by using these functions and simulations of potential earthquake damage within the next 50 years for four major risk populations—structures, personal property, mortality, and injuries.

● **8.1-3** Algermissen, S. T., McGrath, M. B. and Hanson, S. L., **Development of a technique for the rapid estimation of earthquake losses,** *Open-File Report 78-440,* U.S. Geological Survey, Denver, 1978, 98.

A simple, general technique is outlined for the rapid approximate estimation of building losses resulting from ground shaking during earthquakes and is applied to the San Francisco Bay Area. The technique outlined for the estimation of ground shaking damage depends upon building classification, building inventory, loss-ground shaking (intensity), and intensity-attenuation relationships developed in previous studies. The general method can be used anywhere, but is dependent upon inventory development, regional construction practices, and adjustment of loss-intensity and intensity-attenuation relationships to fit the area considered. The method can be used by federal, state, and local agencies involved with disaster preparedness and post-earthquake relief and rehabilitation.

● **8.1-4** Algermissen, S. T., Steinbrugge, K. V. and Lagorio, H. J., **Estimation of earthquake losses to buildings (except single family dwellings),** *Open-File Report 78-441,* U.S. Geological Survey, Denver, 1978, 161.

This study is the eleventh in a series of investigations, beginning in 1967, which pertain to the estimation of earthquake damage to various types of buildings. A methodology is developed in this report for determining inventory and estimating losses resulting from various postulated earthquakes occurring individually and for various ensembles of earthquakes. Five broad classes of buildings are considered. The building classes studied cover most types of buildings in the San Francisco Bay Area, with the exception of one- to four-family dwellings, lifeline facilities, and special types of structures such as oil refineries and storage facilities, military installations, and bridges. One- to four-family dwellings were considered in an earlier report. This methodology, based on the seismic records, ground

● *See **Preface**, page v, for availability of publications marked with dot.*

shaking, construction practices, and building inventory in the San Francisco Bay Area can be adapted, with appropriate adjustments, for use in obtaining rough estimates of probable earthquake losses in other areas of the country.

● 8.1-5 Alderson, M. A. H. C., **A method for the estimation of the probability of damage due to earthquakes,** *Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology,* Vol. K(a), Paper K 2/4 9. (For a full bibliographic citation, see Abstract No. 1.2-20)

A method for the determination of the probability of seismic structural damage to nuclear power plants is described. A poisson distribution for the occurrence of earthquakes has been assumed and the sensitivity of using either a truncated linear magnitude frequency law or one based on extreme values over finite time intervals has been investigated. The analysis has been carried out in terms of site intensity, this being considered to be the parameter of interest related to damage levels, and suitable attenuation relationships have been employed to construct an annual probability distribution of the exceeding of a particular site intensity in terms of the intensity at the site. The sensitivity of the results to several analytical approximations of this distribution has also been investigated. The manner in which the occurrence statistics have been linked to the probability of damage to the plant is fully described. Damage evaluation studies of past earthquakes have indicated that the actual damage to a structure appears to fit a log normal distribution for a given site intensity. By a process of normalization and substitution, it has been shown that the effective resistance to loading of the structure is normally distributed with respect to a normalized site intensity. This normal distribution can be completely defined by assuming a value for the standard deviation and a value for the failure probability at the design level, enabling the overall risk level per year of failure to be computed for a given design level. A range of values for the standard deviation covering structures, pipework, and equipment has been used in the analysis. Improvements have also been made to the model by incorporating the effects of uncertainty in the seismicity parameters. Correction factors for this uncertainty have been derived and applied to the results, although in general the effects are small.

Application of the work to typical conditions in the United Kingdom shows that a reasonable approximation to the curve of the probability of the intensity being exceeded can be made by assuming a truncated second-derivative-type distribution. The difference between assuming a truncated linear magnitude frequency law and one based on extreme values has also been found to be small. The analysis has demonstrated that the contribution from the more frequent but less severe earthquakes in far from negligible in relation to the total risk of structural damage.

● 8.1-6 **Learning from earthquakes. project report 1973-1979,** Earthquake Engineering Research Inst., Berkeley, California, 1979, 93.

● 8.1-7 Lee, Y. T., Okrent, D. and Apostolakis, G., **An evaluation of the incremental seismic risk due to the presence of nuclear power plants,** *UCLA-34P252-02,* Chemical, Nuclear, and Thermal Engineering Dept., Univ. of California, Los Angeles, Dec. 1978, 39. (Also published in *Nuclear Engineering and Design,* **53**, *1*, June 1979, 141-154.)

The seismic risk for the continental United States, in terms of the expected annual number of deaths and severe injuries and the expected property damage, is evaluated in this work. Probabilistic models and correlations are developed and used in the evaluations of the risks, accounting for such important variables as the variability of property values, damage factors, and so on. In addition, the incremental seismic risk resulting from the presence of nuclear power plants is evaluated utilizing results and methods available in the literature. The results show that the incremental risk is generally very small compared to the background seismic risk, even if a very high probability for core melt is postulated.

8.2 Studies of Specific Earthquakes

● 8.2-1 Ifrim, M., **Earthquake of March 4, 1977 in Romania—damage and strengthening of structures,** *Third Canadian Conference on Earthquake Engineering,* Canadian National Committee for Earthquake Engineering et al., Montreal, Vol. 2, 1979, 1277-1306.

This paper discusses the effects of the strong earthquake in Romania on Mar. 4, 1977. Factors which contributed to the disastrous effects of this earthquake are treated and a short description is given of the earthquake damage and the behavior of buildings. The paper concludes with some of the author's viewpoints on the evaluation and strengthening of structures damaged by the earthquake, based on personal experience and observations of the effects of the earthquake.

● 8.2-2 Iwasaki, T. and Kawashima, K., **Damage to civil engineering structures due to the near Izu-Ohshima earthquake of January 14, 1978,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 129-148.

A severe earthquake hit the middle part of the Izu Peninsula on Jan. 14, 1978. The earthquake registered a magnitude of 7.0 on the Richter scale. The Japan Public Works Research Inst. of the Ministry of Construction

● *See* ***Preface****, page v, for availability of publications marked with dot.*

conducted field investigations on damages to engineering structures, such as highways, tunnels, and bridges, immediately after the earthquake. This paper describes the results of the investigations of the earthquake damages and discusses (1) general characteristics of the earthquake, (2) the topography and geology of the Izu Peninsula, (3) the earthquake ground motions, (4) the statistics of damages, and (5) damages to civil engineering structures.

● 8.2-3 Watabe, M., **Building damage caused by the Miyagi-ken-oki Japan earthquake June 12, 1978,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 363–372.

● 8.2-4 Miller, R. K., **The Santa Barbara earthquake of 13 August, 1978,** *Earthquake Engineering & Structural Dynamics,* 7, 5, Sept.-Oct. 1979, 491–506.

Although the Santa Barbara earthquake was only a moderate seismic event, it was the most destructive earthquake in the United States in 1978, causing more than $7,000,000 damage and at least 65 injuries. Reported Richter magnitudes ranged from 5.1 to 5.7, but estimates based on strong-motion records yielded about 5.8. Because of the geologic features of the earthquake, the intensity of strong shaking was geographically asymmetrical, being much larger in the Goleta area north and west of the epicenter. Peak ground accelerations of 0.40 g were recorded near Goleta, while 0.23 g was recorded closer to the epicenter in Santa Barbara. The duration of strongest shaking was only about 2-3 sec. The earthquake caused light cracking of shear walls in multistory reinforced concrete structures, as well as damage to highway overcrossings, many mobile homes, and rooftop mechanical equipment. This paper presents the results of preliminary investigations of the engineering features of this earthquake.

● 8.2-5 Glass, R. I. et al., **Earthquake injuries related to housing in a Guatemalan village–aseismic construction techniques may diminish the toll of deaths and serious injuries,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 31, 19.

The Feb. 4, 1976, Guatemala earthquake devastated a large area and caused 22,778 deaths and 76,504 injuries. In the aftermath of the disaster, the patterns of death and serious injury were studied in the village of Santa Maria Cauque and related to the different types of construction used in the town. In particular, the authors wished to determine which types of building materials and which designs of houses currently in use were most effective in preventing major trauma. It was found that, as in other natural disasters, the risk of serious or fatal injury was greatest to the young and the elderly. A "best house, worst house" prediction model is presented which was developed by surveying all the households in the village and relating the type of construction materials and design to the extent of injury to the occupants. The "worst" houses proved to be old structures made of adobe brick and crowded with more than seven people. The "best" houses were the nonadobe structures. The type of roof, size and number of rooms, and the number of doors and windows did not seem to matter.

● 8.2-6 von Hoegen, M., **Effects of the February 4, 1976 earthquake on human settlements in Guatemala** (Efectos del terremoto del 4 de febrero de 1976 sobre los asentamientos humanos de Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 35, 16.

● 8.2-7 Husid, R. and Arias B., J., **Damage in Guatemala City and vicinity due to the February 4, 1976, earthquake,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 54, 40.

The Guatemalan earthquake of Feb. 4, 1976, caused severe damage to adobe, bajareque, masonry, and reinforced concrete structures in Guatemala City and vicinity. Most of the damage resulted from deficiencies in construction practices and poor quality of construction materials; some damage also resulted from lack of lateral resistance in design. Widespread collapse of adobe and bajareque, severe damage to masonry, and considerable damage to reinforced concrete structures occurred north of Guatemala City. Widespread collapse of adobe and bajareque also occurred to the southwest. In addition, several silos and water tanks failed. To the northwest, a number of reinforced concrete structures collapsed, elevated steel water tanks sustained considerable damage, and adobe and bajareque structures failed. Hospitals everywhere sustained severe damage. The earthquake interrupted lifeline systems throughout Guatemala, including water pipes, highways, railways, and telephone and electric lines.

In damaged reinforced concrete columns, it was common to find ties too widely spaced. Failures of short reinforced concrete columns were caused by a lack of masonry walls in the original design. Failure was common in masonry walls without edge members. The few steel buildings behaved very well. Corrugated-steel grain silos failed by rupturing.

Secondary faulting in a number of subdivisions in Guatemala City caused localized severe damage. Ground failures occurred in several areas of the city. Many landslides were observed in the barrancos, and some of them

● *See **Preface**, page v, for availability of publications marked with dot.*

were responsible for the complete loss of one- and two-story structures. From a detailed damage survey of Guatemala City, damage ratios (i.e., cost of repair/replacement cost) were estimated for individual constructions. Average values per block were assessed for the whole city. The Etisa, a reinforced-concrete office building, sustained severe damage as evidenced by a damage ratio of 0.56. Similar damage ratios were calculated for a number of other reinforced concrete structures and also for the Agua Caliente bridge. A map of the city showing damage ratios for more than 260 individual structures is presented using a 5-point damage scale. A detailed average damage ratio map for zones 1 through 6 (Guatemala City) is also presented. Both maps are compared with the previously obtained modified Mercalli intensity distribution for the city.

● 8.2-8 Papstamatiou, D. J., **The 1978 Chalkidhiki earthquakes in N. Greece-a preliminary field report and discussion,** *TN-LN-28,* Dames & Moore, London, Nov. 1978, 45.

The objective of the project was to conduct a field study of those features of the 1978 Chalkidhiki (Thessaloniki) earthquakes pertinent to the design of structures in similar seismotectonic environments. The earthquake area was visited on June 28, 1978, eight days after the main shock of June 20. The field study covered both ground and structural response. Ground response was particularly interesting in the epicentral region which presented a post-earthquake pattern of intensive ground deformation. This pattern was recorded on 1:50,000 maps, because aerial photographs were not available. In the epicentral area, only the response of simple rural structures was obtained since there were no major structures in the area. Farther from the epicenter, structural response only was examined. For this purpose, Thessaloniki, the closest city to the earthquakes, presented the best case for study.

● 8.2-9 Johnson, E. K. and Winch, T. R., **Trip report: UCSB earthquake damage survey,** *SLAC TN-79-1,* Stanford Linear Accelerator Center, Menlo Park, California, Jan. 1979, 19.

On Sept. 25, 1978, the authors visited the Santa Barbara campus of the Univ. of California to gather information regarding the earthquake that occurred on Aug. 13, 1978. This note summarizes the results of that visit. Included in the report are a list of the people interviewed; a review of the basic systems involved and how the systems performed following the earthquake; a summary of the remarks of various individuals regarding disaster planning, followup problems, and the level of support for earthquake safety planning; general comments and observations; and a copy of the emergency procedures of the Facilities Management Dept. of the university.

● 8.2-10 Yuxian, H., **Some engineering features of the 1976 Tangshan earthquake,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1-9. (Bound separately as "Special Session on Earthquake Engineering in China [papers].")

The following aspects of the 1976 Tangshan earthquake are discussed: seismology and geology, damage to structures including structures not designed to withstand earthquakes, failure of smokestacks, strong-motion records, and general conclusions.

● 8.2-11 Dasheng, C., **Field phenomena in meizoseismal area of the 1976 Tangshan earthquake,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 23-37. (Bound separately as "Special Session on Earthquake Engineering in China [papers].")

The 1976 Tangshan earthquake (M_s = 7.8) is the most severe earthquake ever to have occurred in a densely populated industrial mining city in China. In Tangshan and vicinity, many people were killed by collapsing structures; however, miners working underground in the Kailuan coal mine were able to escape safely. In the southern part of Tangshan and Fengnan County, a maximum horizontal ground slippage of 1.53 m and a maximum vertical ground slippage of 0.8 m were observed. In the meizoseismal area, most buildings and structures on the ground either totally collapsed or suffered serious damage, while most of the underground structures, including basements, suffered only slight damage. The exceptions were the heavily damaged tunnels along both banks of the Dou River. Professional groups conducted field investigations in the area, and this report presents the results of the investigations.

● 8.2-12 Yaoxian, Y. and Xihui, L., **Experience in engineering from earthquake in Tangshan and urban control of earthquake disaster,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1-22. (Additional papers bound separately in second half of "Special Session on Earthquake Engineering in China [papers].")

The 1976 Tangshan earthquake is one of the most severe earthquakes ever recorded. In this paper, the causes of the earthquake are outlined, the damage to buildings, lifeline systems, and equipment are investigated, and secondary disasters and the related problems of urban planning are discussed. Also included are discussions of developments in repairing and strengthening existing buildings and developments in seismic-resistant design and research that have occurred in China since the earthquake.

● 8.2-13 Guoliang, J., **Damage in Tianjin during Tangshan earthquake,** *Proceedings of the 2nd U.S. National*

Conference on Earthquake Engineering, Earthquake Engineering Research Inst., Berkeley, California, 1979, 39–59. (Additional papers bound separately in second half of "Special Session on Earthquake Engineering in China [papers].")

The magnitude of the Tangshan earthquake of July 28, 1976, was 7.8. The epicenter was at Tangshan, and the focal depth ranged between 12 and 16 km. The intensity of the earthquake at the epicenter was 11 on the new Chinese intensity scale, which is similar to the Modified Mercalli Intensity Scale. The intensity in the urban center of Tianjin, about 100 km from the epicenter, was 8, while the intensity in the suburbs and surrounding counties varied from 7 to 9. An isoseismal intensity map is shown for Tianjin, Beijing, and Tangshan. From the map, it can be seen that in the urban areas in Tianjin the intensity was abnormally high; this was the result of backfills and soft soils in the area. Tianjin is more than 100 km southeast of Beijing and is the third largest city in China. Most of the structures in the city were constructed almost 100 years ago. The city contains structures of many types, including many industrial structures. Most governmental buildings are constructed of brick and timber or brick and concrete. Industrial structures are primarily built with concrete frames, or are reinforced concrete single-story structures. Many factories have brick chimneys. This paper describes the damage to structures in Tianjin, the seismic-resistant strengthening measures used to repair structures, and the secondary damage caused by the earthquake.

● **8.2-14** Okubo, T. and Ohashi, M., **Miyagi-ken-oki, Japan earthquake of June 12, 1978—General aspects and damage,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 15. (Papers from Session 5A; bound separately.)

This paper describes the seismological aspects of the June 12, 1978, Miyagi-ken-oki earthquake, the seismicity and the geological and subsoil conditions of the area, the recorded and estimated intensities of ground vibration, and the statistics and characteristics of damage caused by the earthquake.

● **8.2-15** Blume, J. A. et al., **Damage prediction for an earthquake in Southern California: a program for predicting the structural effects of a major earthquake in the region of the Palmdale Uplift,** *JABE/USGS-7640*, URS/John A. Blume & Assoc., San Francisco, Feb. 1978, rev. Apr. 1979, 154.

The objective of this study was to estimate the nature and distribution of damage to structures in the southern California area caused by a hypothetical earthquake which is located on the San Andreas fault, has a rupture length of 300 km, and spans the area between Cholame to the north and Cajon Junction to the south. Its Richter magnitude was given as 8.1. The Engineering Intensity Scale (EIS) technique was used to make the damage estimation. Two unique features of the EIS technique, which establish the nature and character of the predictions made, are (1) damage is established from response spectrum values of ground motion, and (2) damage estimates consist of a definition of the areas in which structures might be damaged and a general evaluation of the incidence and degree of damage that such structures might sustain. Detailed structural inventories are beyond the scope of this evaluation, but exposure in the affected area is generally identified.

● **8.2-16** Real, C. R., McJunkin, R. D. and Leivas, E., **Effects of Imperial Valley earthquake: 15 October 1979, Imperial County, California,** *California Geology*, 32, *12*, Dec. 1979, 259–265.

This article summarizes information collected by the authors shortly after the Oct. 15, 1979, Imperial Valley earthquake. Included are discussions of the geologic setting and seismic history of the area, the surface faulting caused by the earthquake, the acceleration data, and a comparison of the May 18, 1940, and the Oct. 15, 1979, Imperial Valley earthquakes.

● **8.2-17** Philbrick, R. A. and Owen, G. N., **Santa Barbara, earthquake of August 13, 1978: field data report,** *JAB-00099-124*, URS/John A. Blume & Assoc., San Francisco, Aug. 1979, 88.

On Aug. 31 and Sept. 1, 1978, a field study was conducted of the damage inflicted on structures in the Greater Santa Barbara area by a magnitude 5.1 earthquake that occurred there on Aug. 13, 1978. The study was undertaken to determine the general nature and extent of damage to all types of structures. Particular attention was given to the damage sustained by mobile homes because the damage to these structures during the earthquake was more extensive than expected. Other structures included in the field study were the Univ. of California, Santa Barbara, buildings, Santa Barbara County government buildings, and private buildings. The results of this field study combined with the results of other, similar studies can be used to determine relationships between ground motion and damage. The data collected will be useful to earthquake engineers working to improve analytical procedures for predicting damage inflicted on structures by ground motion.

● **8.2-18** **Study of the Caracas earthquake of July 29, 1967, part 2** (Segudna fase del estudio del sismo ocurrido en Caracas el 29 de Julio de 1967, in Spanish), Fundacion Venezolana de Investigaciones Sismologicas, Ministerio de Obras Publicas, Venezuela Comision Presidencial para el Estudio del Sismo, Caracas, 1978, 2 vols., 1281.

● **8.2-19** Blume, J. A. and Stauduhar, M. H., eds., **Thessaloniki, Greece earthquake, June 20, 1978; reconnaissance report,** Earthquake Engineering Research Inst., Berkeley, California, Jan. 1979, 86.

This report summarizes the results of an extensive reconnaissance investigation conducted in the Thessaloniki area during the period from May 24, when the first foreshock was felt, until a few days after the seismic events of June 20. Supplementary information, including suggested explanations for the pattern of building response exhibited in Thessaloniki, made available by several technical centers in Greece as well as by public and private organizations in Greece and elsewhere is also reported. However, because much of the investigative work was carried out while the earthquakes were still occurring, no attempt at rigorous interpretation of the collected data is made. Aspects of the June 20 event that appear to warrant further investigation are identified, but the central purpose of this report is to document the reconnaissance work, focusing primarily on the magnitude 6.5 shock of June 20 and its effect on structures. Background information helpful to an understanding of the June 20 earthquake and its effects, including brief discussions of the cultural-political history of Thessaloniki, its environmental setting, its geology and soils, and the history of the area's seismicity, is provided. The faulting in the epicentral area of the June 20 event is described, the earthquake-generation mechanism is discussed, and data from records obtained from the instruments of several seismological networks that were installed before and after the June 20 shock are presented. Descriptions are included of building damage from the June 20 earthquakes in the context of seismic codes, construction practice, and soils and economic and property loss data are reported, and some of the sociological effects of the earthquake sequence are discussed.

● **8.2-20** Stratta, J. L. and Wyllie, Jr., L. A., **Friuli, Italy earthquakes of 1976; reconnaissance report,** Earthquake Engineering Research Inst., Berkeley, California, Aug. 1979, 97.

This report describes the general and socioeconomic observations of the reconnaissance team, the landslides that occurred, and the damage to such structures as multistory and industrial structures and bridges. Included in the report are a bibliography of articles and publications concerning the earthquakes and an appendix, "Tectonic, Geologic, and Geotechnical Aspects of the 1976 Friuli Earthquakes."

● **8.2-21** Basili, M. et al., **The Montenegro earthquake of April 15, 1979** (Il terremoto del Montenegro del 15 aprile 1979, in Italian), Ist. Poligrafico e Zecca dello Stato, Rome, 1979, 66.

Some engineering, geological, and geophysical features of the 1979 Montenegro, Yugoslavia, earthquake are illustrated. They were observed during a one-week trip in the epicentral area made by a delegation from the Italian Ministry of Public Works. A preliminary analysis of seismometric data is presented to give a possible example of the model of the seismogenetic mechanism.

● **8.2-22** Ambraseys, N. N., Arsovski, M. and Moinfar, A. A., **The Gisk earthquake of 19 December 1977 and the seismicity of the Kuhbanan fault-zone,** *Technical Report RP/1977-78/2.1614.1,* United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris, 1979, 47.

On Dec. 19, 1977, a severe earthquake occurred in east-central Iran, causing considerable damage and loss of life. This report contains the general observations and findings of a UNESCO reconnaissance mission sent to Iran to study the effects of the earthquake in the province of Kerman and to investigate its past seismicity. Also included in the report is a summary of information collected during this visit about earlier earthquakes in the region.

● **8.2-23** Hakuno, M. et al., **A report on the damage to civil engineering structures caused by the Miyagi-ken oki earthquake of 1978** (in Japanese), *Bulletin of the Earthquake Research Institute,* **54,** *Part 2,* 1979, 351-398.

The Miyagi-ken-oki earthquake (M = 7.4), which occurred on June 12, 1978, in Japan, caused considerable damage in Sendai and vicinity. This paper describes the damage to various types of structures, including road and highway structures; railroads; ports and harbors; water supply, sewage, electric power, communication, and gas supply systems; and oil tanks. Also discussed are ground liquefaction, landslides and land failures, and damage to river embankments. The 1978 earthquake is compared with an earthquake of similar magnitude and epicenter which struck Sendai in 1936.

● **8.2-24** Hakuno, M., **A report on the damage by the Shimane-ken chubu earthquake of 1978** (in Japanese), *Bulletin of the Earthquake Research Institute,* **54,** *Part 1,* 1979, 211-222.

This paper summarizes damage caused by the Shimane-ken chubu earthquake of 1978 in Japan. Because of the earthquake's small magnitude, damage to structures was slight. No dwellings collapsed and no human lives were lost. The most severe damage to structures was the partial collapse of four houses and several warehouses, small cracks in road pavement, and small-scale landslides on cut slopes. Because the region is mountainous, it does not have thick alluvium deposits. The maximum ground acceleration was estimated to exceed 300 gals. Most lifeline systems, such as roads and electricity and water supply systems, suffered a greater degree of failure than dwelling

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

structures. The damage to lifeline systems was especially remarkable in this earthquake because damage to other structures was not severe.

8.3 Effects on Buildings

● 8.3-1 Scawthorn, C., Yamada, Y. and Iemura, H., **Statistical studies of low-rise Japanese building damage: the Miyagiken-oki earthquake of June 12, 1978,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 373-382.

Damage data for Sendai, Japan, resulting from the Miyagi-ken-oki earthquake of June 12, 1978 (M = 7.4), were collected and processed to provide damage ratios for buildings and monetary estimates of the damage. The data are for damage to lowrise residential structures, mostly of wood construction. Spectral accelerations in Sendai were determined using a "virtual epicenter," moved towards Sendai from the epicenter of record, together with existing spectral acceleration regressions. Damage ratios were found to correlate best with response spectral accelerations at a period of 0.75 sec. A relationship between spectral acceleration and damage cost estimates was obtained by combining correlations determined in the paper.

● 8.3-2 Iordachescu, E. et al., **Statistical survey of the performance of one standard-design type of high-rise reinforced-concrete shear-wall apartment buildings, in Bucharest, during the March 4, 1977, Romania earthquake,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 803-812.

● 8.3-3 Wyllie, Jr., L. A. and Poland, C. D., **A documented vertical acceleration failure,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 1066-1075.

Hinges were observed in post-tensioned beams supporting a concrete canopy in a service station in Managua, Nicaragua, after the Dec. 23, 1972, earthquake. The hinging appeared to be caused by vertical accelerations. A series of analyses, including a time-history analysis with a three-dimensional model, confirmed that the post-tensioned beam hinging was caused by the vertical component of motion which produced a larger moment at an earlier time than the horizontal motion during the simulated event.

● 8.3-4 **Reports concerning damages on steel structures caused by the off Miyagi Prefecture earthquake of 1978** (in Japanese), *JSSC, Society of Steel Construction of Japan,* **14,** *153,* 1978, 1-56.

● 8.3-5 **Reports concerning damages on the buildings and Oster structures caused by the Izu-Oshima earthquake of January 1978, as to steel structures and reinforced concrete structures in Inatori** (in Japanese), *JSSC, Society of Steel Construction of Japan,* **14,** *152,* 1978, 19-45.

● 8.3-6 Gonzalez, H. and Serrano, J. A., **Project for educational investment in the area affected by the February 4th., 1976 earthquake** (Proyecto para la inversion educativa en el area afectada por el terremoto del dia 4 de febrero de 1976, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 24, 23.

This paper reports on a study developed under the auspices of the Guatemalan Ministry of Education and the Organization of American States (OAS). Its main objective was to determine and quantify damage caused by the Feb. 4, 1976, Guatemala earthquake to educational installations in the affected area. The results of the study were necessary to establish priorities for different areas depending upon the degree of destruction and the educational needs of the area. Approximately 2190 school buildings were analyzed, of which 522 are located in urban areas and 1677 in rural areas. The study indicated that 38% needed to be totally rebuilt, 17.8% needed major repairs, and 44.2% needed minor repairs.

● 8.3-7 Bonilla P., H. R., **Cost evaluation and estimates of damages caused by the 4 February 1976 Guatemala earthquake on houses built under F.H.A. insurance** (Evaluacion y estimacion de costos de los danos ocasionados por el terremoto del 4 de febrero de 1976, en las viviendas construidas bajo aseguramiento del F.H.A., in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 21, 19.

This paper discusses the following: (1) damage caused by the Feb. 4, 1976, Guatemala earthquake to the exterior of houses; (2) damage to the interior of houses; (3) the integration of field data regarding the number of claims submitted by tenants to the Inst. de Fomento de Hipotecas Aseguradas (FHA) and banking institutions; (4) the computation of damages on the basis of different building items and the standardization of estimates and computation references; (5) the percentage of damages relative to 1976 costs for different types of houses, with reference to the original costs.

Approximately 550 houses were damaged by the earthquake. Of a total of 10,000 houses built under FHA insurance, 5.44% were damaged. Of these, 93 were totally destroyed, mainly because of their proximity to surface ruptures. These 93 dwellings represent 0.93% of the total

● *See* ***Preface****, page v, for availability of publications marked with dot.*

houses built and 17.1% of the damaged houses. The remainder of the damaged houses (451) suffered damage to the interior and exterior walls; a damage/cost ratio of 60% to 1% of the worth of the house is estimated.

● 8.3-8 Hermosilla, J. J., **The behavior of different structural systems in concrete buildings during the Guatemalan earthquake** (El comportamiento de diferentes sistemas estructurales en edificios de concreto en el terremoto de Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 59, 6.

● 8.3-9 Yerlici, V. A., **Performance of reinforced concrete buildings in the March 4, 1977 Romanian earthquake,** *Concrete International,* 1, 9, Sept. 1979, 52–57.

An earthquake of magnitude 7.2 on the Richter scale shook the southern region of Romania on Mar. 4, 1977. Bucharest, with a population of 2,000,000 people, was the urban center hit hardest by the shock. Approximately 1300 people in Bucharest were killed, 34,000 families were left homeless, 32,000 flats were heavily damaged, 35 multistory reinforced concrete buildings completely collapsed, and minor structural damage and serious nonstructural damage occurred in a great number of buildings.

A rich variety of modern reinforced concrete structures exist in Bucharest. The state-of-the-art of earthquake engineering in Romania is quite up to date. The ground motion of the Mar. 4, 1977, shock was recorded in Bucharest by a strong-motion accelerograph and a seismoscope. A microzoning map was available for the city. A modern code for earthquake-resistant design and construction was in effect, and there existed a vast state-operated building industry. The presence of all these conditions rendered earthquake-stricken Romania a unique test site. This article reports some first-hand observations made by the author of the performance of various types of reinforced concrete buildings in Bucharest during the earthquake. The observed behavior of structures and the measured ground motions are interpreted, and certain general conclusions are reached with respect to the earthquake performance of multistory prefabricated panel construction, multistory monolithic frame building, truss bracing of frames, and heavy masonry partitions.

8.4 Effects on Miscellaneous Structures and Systems

● 8.4-1 Mathews, W. H., **Landslides of central Vancouver Island and the 1946 earthquake,** *Bulletin of the Seismological Society of America,* **69**, 2, Apr. 1979, 445–450.

Numerous fresh landslide scars visible in aerial photographs of central Vancouver Island taken in the period 1946 to 1957 are attributed to the magnitude 7.2 earthquake of June 23, 1946. Distribution of the scars shows a very strong concentration in a zone parallel to the favored fault-plane solution but some 50 km to one side, straddling the favored P nodal auxiliary plane. Topography precludes the development of a corresponding belt of landslides on the opposite side of the favored fault plane. A high proportion of slides face southerly or southwesterly but an explanation for this favored orientation is lacking.

● 8.4-2 Sylvester, A. G., **Earthquake damage in Imperial Valley, California May 18, 1940, as reported by T. A. Clark,** *Bulletin of the Seismological Society of America,* **69**, 2, Apr. 1979, 574–568.

U.S. Bureau of Reclamation civil engineer T. A. Clark surveyed and photographed damage to water distribution systems on both sides of the International Boundary between California and Mexico immediately following the Imperial Valley, California, earthquake of May 18, 1940. His report, written only weeks after the earthquake, focusses on damage caused by horizontal surface rupturing, shaking, lurching, and, to a lesser degree, liquefaction to such engineered structures as aqueducts, canals, flumes, roads and bridges. Clark's report and photographic illustrations are a valuable supplement to the relatively sparse amount of structural engineering data previously available for such an important seismic event in California's earthquake history.

● 8.4-3 Katayama, T., **Damage to lifeline systems in the city of Sendai caused by the 1978 Miyagiken-oki earthquake,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 3, 1979, 588–604.

The city of Sendai, with a population of 617,000 was struck by a destructive earthquake of magnitude 7.4 on June 12, 1978. One of the particular features of the Miyagiken-oki earthquake was the damage sustained by various lifeline utility systems. This paper describes the damage to electric power, water supply, sewage, and gas systems in Sendai, and their restoration.

● 8.4-4 Isenberg, J., **Role of corrosion in water pipeline performance in three U.S. earthquakes,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 683–692.

Earthquakes cause damage to underground water pipelines as shown during the 1965 Puget Sound, the 1969 Santa Rosa, and the 1971 San Fernando earthquakes. Immediate causes of pipe failures in regions where ground

● *See **Preface**, page v, for availability of publications marked with dot.*

warping and rupture occur include buckling, round cracks (circumferential splitting), and joint and valve failures. However, within the area affected by each of the three earthquakes mentioned above, there is a region where ground shaking is dominated by wave effects and where pipeline damage also occurs. This paper describes the seismic performance of pipelines subjected primarily to wave propagation effects. Data from such regions suggest that a strong correlation exists between poor seismic performance and advanced corrosion in cast iron and steel pipes. This evidence helps to justify corrosion control programs that are in effect at some major utilities and the practice of replacing reaches of pipe that leak excessively. Although replacement can be justified economically without considering the probability of an earthquake, replacement schedules may be modified when earthquakes are considered. Seismic risk analyses can and probably should consider the condition of a pipe in terms of a strength parameter which varies with a corrosion-related parameter, such as soil resistivity, in much the same way that ground shaking has been related to topography.

● 8.4-5 Kubo, K., **Effect of the Miyagi-oki, Japan earthquake of June 12, 1978 on lifeline systems,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 343–352.

This paper describes the damage caused by the Miyagi-ken-oki earthquake of June 12, 1978, to gas and water supply systems and to railway and highway structures in Sendai.

● 8.4-6 Kuribayashi, E. et al., **Damage to highway bridges and other lifeline systems from the Miyagi-ken-oki, Japan earthquake of June 12, 1978,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 353–362.

● 8.4-7 Garwood, N. C., Janos, D. P. and Brokaw, N., **Earthquake-caused landslides: a major disturbance to tropical forests,** *Science,* **205,** *4410,* Sept. 7, 1979, 997–999.

Earthquakes occasionally denude large areas of tropical forest: for example, 54 sq km in Panama in 1976 and 130 sq km in New Guinea in 1935. Earthquake rates in New Guinea, but not in Panama, are sufficiently high so that substantial areas of disturbed, nonclimax forest may accumulate. In New Guinea, earthquake-caused landslides are as important as tree falls in the disturbance regime.

● 8.4-8 Katayama, T. et al., **Effect of the Miyagiken-oki earthquake of June 12, 1978, on city gas systems** (in Japanese), *Seisan-Kenkyu,* **31,** *2,* Feb. 1979, 18–40.

● 8.4-9 Hansen, K. D. and Roehm, L. H., **The response of concrete dams to earthquakes,** *International Water Power & Dam Construction,* **31,** *4,* Apr. 1979, 27–31.

This article describes the seismic response of six concrete dams which have withstood large earthquakes. The earthquake names and dates appear in parentheses following the dam names. The dams include the Lower Crystal Springs Dam in northern California (1906, San Francisco); the Blackbrook Dam in Leicestershire, England (1957); the Hsinfengkiang Dam in Kwangtung Province, China (1962); the Koyna Dam in southwestern India (1967); the Pacoima Dam in southern California (1971, San Fernando); and the Ambiesta Dam in northern Italy (1976, Friuli). It is found that, in general, concrete dams have performed extremely well when subjected to earthquakes. Even when shaken by forces far in excess of design loadings, the structures have responded without loss of the reservoir or irreparable damage.

● 8.4-10 Katayama, T., Masui, Y. and Isoyama, R., **Effect of the Miyagiken-oki earthquake of June 12, 1978, on sewerage systems** (in Japanese), *Seisan-Kenkyu,* **31,** *7,* July 1979, 22–27.

● 8.4-11 Katayama, T. and Masui, Y., **Effect of the Miyagiken-oki earthquake of June 12, 1978, on electric power supply system** (in Japanese), *Seisan-Kenkyu,* **31,** *6,* June 1979, 14–18.

● 8.4-12 Katayama, T. et al., **Effect of the Miyagiken-oki earthquake of June 12, 1978, on water supply systems** (part 1) (in Japanese), *Seisan-Kenkyu,* **31,** *4,* Apr. 1979, 1–7.

● 8.4-13 Katayama, T. et al., **Effect of the Miyagiken-oki earthquake of June 12, 1978, on water supply systems** (in Japanese), *Seisan-Kenkyu,* **31,** *6,* June 1979, 7–13.

● 8.4-14 Katayama, T., **Damage to lifeline systems in the city of Sendai caused by the 1978 Miyagiken-oki earthquake,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **12,** *1,* Mar. 1979, 49–65.

The city of Sendai, with a population of 617,000 was struck by a destructive earthquake of magnitude 7.4 at 17:14 (JST) on June 12, 1978. One of the particular features of the Miyagiken-oki earthquake was the damage sustained by various lifeline utility systems. This paper describes the damage to electric power, water supply, sewage and gas systems in Sendai, and the restoration process. The paper includes photographs of damaged structures.

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

● **8.4-15** Kobayashi, Y., **A catastrophic debris flow at Nebukawa in the great Kanto earthquake, 1923** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **32,** *1,* Mar. 1979, 57-73.

The Kanto earthquake of 1923 triggered a catastrophic flow of soils and rock which devastated the village of Nebukawa with a loss of 300 to 400 lives. The buried area at Nebukawa is determined by synthesizing eyewitness accounts, photographs, the character of surface soils, etc. From the eyewitness accounts and aftershock records, it is estimated that the flow began about five minutes after the main shock. The temporal change in topography in the mountain region is investigated by comparing maps of the topography of the area before and after the earthquake, and a probable source of the flow is assumed to be a large depressed area, Obora, about 4 km upstream from Nebukawa. The grain-size distributions of the flow deposits and those of mountain soils are also consistent with this assumption.

● **8.4-16** Harp, E. L., Wieczorek, G. F. and Wilson, R. C., **Earthquake-induced landslides from the February 4, 1976 Guatemala earthquake and their implications for landslide hazard reduction,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 13, 33.

Mapping from U-2 aerial photographs indicates that the Feb. 4, 1976, earthquake (M 7.5) in Guatemala triggered more than 10,000 landslides. Follow-up field studies indicate that the regional landslide distribution was a function of seismic intensity, bedrock lithology, topography, and the orientation and location of regional fracture systems. The greatest landslide incidence occurred in the Pixcaya and Xaltaya river valleys in the highlands west of Guatemala City. Most of the seismic-induced landslides were rockfalls and shallow debris slides of less than 15,000 m^3, and roughly 90% of the total number were situated within Pleistocene pumice deposits. The remainder occurred mainly within volcanic rocks of Tertiary age.

There were 11 large individual deep-seated landslides. All 11 blocked stream drainages, four forming sizable slide-dammed lakes, thereby creating potential hazards from flooding and subsequent overtopping and catastrophic reservoir breaching. The post-earthquake investigation provided insight into the generation of seismic-induced landslides and the behavior of existing landslides under strong shaking conditions: (1) The distribution of landslides, especially within the pumice deposits, suggests that the onset of earthquake-generated landsliding occurs at a much lower shaking intensity than would be indicated by a rating of X on the Modified Mercalli Scale. (2) Contrary to prior expectation, pre-existing landslides showed few indications of unstable behavior during the earthquake. (3) Field evidence indicates that seismic-induced rockfalls and debris slides were confined to the steepest slopes (=> 30-50° for debris slides and > 50° for rockfalls) and occur at or near slope crests. Their extensive development on narrow ridges and promontories indicates that the existing topography has a great influence on the level of ground motion amplification and the locations of these slides. The restricted areal distribution of seismic-induced rockfalls and debris slides may permit regional mapping of the susceptibility for these types of failures using a few simple parameters such as slope and lithology.

● **8.4-17** Marcuson III, W. F., **Visit to Japan to observe damage which occurred during the near Izu Oshima earthquakes, January 14 and 15, 1978,** *Misc. Paper GL-79-20,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1979, 48.

The magnitude 7.0 earthquake near Izu-Oshima occurred at 12:24 p.m. on Jan. 14, 1978. The main aftershock occurred on Jan. 15 and had a magnitude of 5.7. These two earthquakes are believed to have caused liquefaction of tailings and two dam failures which resulted in 80,000 m^3 of tailings flowing down the mountainside and into a stream. The tailings, containing sodium cyanide, contaminated the stream all the way to the Pacific Ocean, a distance of 30 km. The tailings dams were approximately 30 m high and were constructed using the upstream construction method. These dams had been previously analyzed pseudostatically using a seismic coefficient of 0.2. This case history clearly indicates that a pseudostatic analysis using routine static soil properties as input is not appropriate if liquefaction is the mode of failure.

● **8.4-18** Percheron, J. C., **Causes of failure in damaged bridges during the February 4th, 1976 earthquake in Guatemala** (Causa de las fallas de los puentes danados durante el terremoto del 4 de febrero 1976 en Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 62, 13.

Damage to bridges caused by the Guatemalan earthquake of Feb. 4, 1976, varied in severity from superficial damage to total collapse. It was found by observation and analysis of many of the damaged bridges that the amount of damage was directly related to the number of degrees-of-freedom and the quality of coupling. Most of the damage resulted from poor coupling conditions between the superstructures and the substructures. A common weak point has been identified by examination of four bridges illustrating such failure: The Agua Caliente Bridge, the Gualan-Mayuelas Bridge, the Asuncion Bridge, and the El Incienso Bridge. Conclusions and recommendations for the design of bridges in seismic zones are presented.

● *See **Preface,** page v, for availability of publications marked with dot.*

● **8.4-19** Cooper, J. D., **Bridge and highway damage resulting from the 1976 Guatemala earthquake,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 61, 56.

The Guatemala earthquakes of Feb. 4 and 6, 1976, caused severe economic hardships because of highway bridge failures and damage. The damage to three major bridges, Agua Caliente, La Asuncion, and Incienso, is described. A general discussion of damage to bridges and the roadway along a major highway, the Atlantic Highway (Route CA9), is also presented.

● **8.4-20** Yamamura, K. et al., **Ground failures and damages to soil structures from the Miyagi-ken-oki, Japan earthquake of June 12, 1978,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 16. (Papers from Session 5A; bound separately.)

A strong earthquake (M = 7.4) occurred in the Miyagi Prefecture in the northeastern part of Japan on June 12, 1978. This earthquake caused extensive damage to various engineering structures such as buildings, bridges, river dikes, industrial facilities, etc. This paper briefly describes ground failures caused by soil liquefaction and damage to earth dikes. A map showing sites of liquefaction and damage to river dikes is included, and information is given for 30 areas where liquefaction occurred. Soil conditions at some typical sites of liquefaction and assessment of liquefaction potential using soil data from in situ tests, laboratory tests, and response analyses are given. Features of typical damaged river dikes at the Eai, Yoshida, Kitakami, and Natori rivers are described.

● **8.4-21** Steinbrugge, K. V. and Schader, E. E., **Mobile home damage and losses: Santa Barbara earthquake, August 13, 1978,** *SSC 79-06* California Seismic Safety Commission, Sacramento, 1979, 19.

Field observations following the 1978 Santa Barbara, California, earthquake confirmed what had also been observed after the 1971 San Fernando earthquake, namely, that mobile homes suffered much more damage than did nearby conventional wood frame dwellings. Exceptions noted after the 1971 shock were usually related to abnormal geologic conditions such as a dwelling astride a fault rupture, on a landslide, or affected by another geologic hazard. Significant exceptions were not observed after the Santa Barbara shock. Important earthquake experience to mobile homes is limited to these two shocks. The purposes of this paper are to: (1) examine mobile home insured losses in the context of other damage, and (2) compare projected losses for mobile homes with those of conventional wood frame dwellings in the event of a major earthquake. Shown in figures are a regional map showing the location of the city of Santa Barbara and the earthquake study area of this report. Mobile homes are rapidly increasing in number and in insurance importance. A total of 273,034 were sold in California from 1965 through 1977, with 23,938 units sold in 1977. The earthquake study area in Santa Barbara and vicinity contained 1646 insured and noninsured coaches in 14 mobile home parks, of which 118 paid insurance claims in eight of the hardest hit parks are examined in this study. There were relatively few paid claims in the other parks.

● **8.4-22** Marcuson III, W. F., Ballard, Jr., R. F. and Ledbetter, R. H., **Liquefaction failure of tailings dams resulting from the near Izu Oshima earthquake, 14 and 15 January 1978,** *Sixth Panamerican Conference on Soil Mechanics and Foundation Engineering,* Vol. II, 69-80. (For a full bibliographic citation, see Abstract No. 1.2-22.)

The magnitude 7.0 earthquake near Izu Oshima, Japan, occurred at 12:24 p.m. on Jan. 14, 1978. The main aftershock occurred on Jan. 15 and had a magnitude of 5.7. These two earthquakes are believed to have caused liquefaction of tailings and two dam failures which resulted in some 80,000 m^3 of tailings flowing down the mountainside and into a stream. These tailings, containing sodium cyanide, contaminated the stream all the way to the Pacific Ocean, a distance of 30 km. The tailings dams were approximately 30 m high and were constructed using the upstream construction method. These dams had been previously analyzed pseudostatically using a seismic coefficient of 0.2. This case history clearly indicates that a pseudostatic analysis using routine static soil properties as input is not appropriate if liquefaction is the mode of failure.

8.5 Effects and Near Surface Geology

● **8.5-1** Minkov, M. and Evstatiev, D., **On the seismic behavior of loess soil foundations,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 988-996.

In Bulgaria, many structures are constructed on loess soils. This paper examines how the strength and deformation behavior of loess soil bases, within the limits of the active zones under foundations, influenced structural damage during the Romanian earthquake of Mar. 4, 1977. Although significant results were obtained, the effect of the soil bases could be evaluated only qualitatively because it was difficult to assess other factors in determining the damage caused by the earthquake. Complications related to the application of the MSK scale also made evaluation difficult.

● 8.5-2 Armstrong, C. F., **Coyote Lake earthquake—6 August 1979,** *California Geology,* 32, *11,* Nov. 1979, 248-251.

This report is a summary of observations and interpretations of a visit by staff geologists of the California Div. of Mines and Geology to the Coyote Lake-Gilroy, California, area following the earthquake of Aug. 6, 1979. The purposes of the visit were to inspect the Calaveras fault zone for signs of surface displacement resulting from the earthquake, to identify any associated land instability or geologic hazards, and to gather data for fault evaluation relative to the Alquist-Priolo Special Studies Zones.

● 8.5-3 Tatsuoka, F. et al., **Soil liquefaction and damage to soil structure during the earthquake off Miyagi prefecture on June 12th, 1978,** *Bulletin of Earthquake Resistant Structure Research Center,* 12, Mar. 1979, 3-13.

The authors surveyed the area damaged by the earthquake of June 12, 1978, that occurred in the sea off Miyagi prefecture in northern Japan. The Japanese Meteorological Agency estimated the location of the epicenter at 28°09′N and 142°10′E, the depth at 40 km, and a magnitude of 7.4. The results of this survey are examined.

● 8.5-4 Koose S., F., **Study on talus slipping in ravines in Guatemala City** (Estudio de deslizamientos de taludes de barrancos en la Ciudad de Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 12, 15.

Morphologically, the city of Guatemala presents a series of plateaus separated by ravines, ranging from 25 to 150 m in altitude and slopes oscillating between 45° and 90°. A great number of houses are built near the edge of these ravines. During the Feb. 4, 1976, Guatemalan earthquake, slipping occurred in the talus of the ravines in different areas. The slipping destroyed homes and caused loss of human lives.

One of the regions most severely affected by the slipping was an urban area called Lomas del Norte, located in zone 17 in Guatemala City. The Inst. de Fomento de Hipotecas Aseguradas de Guatemala conducted a study of the slips and the conditions of and hazards to these houses located at the edge of the ravines surrounding the area. The text of the report issued by the institute is presented in this paper. Because the soils and prevailing conditions in the ravines of the city of Guatemala are fairly similar, the results of the study of the Lomas del Norte area are considered useful as a preliminary guide in evaluating seismic risks for constructions located at the edge of ravines in the different zones of the city.

● 8.5-5 Hoose, S. N., Wilson, R. C. and Rosenfeld, J. H., **Liquefaction-caused ground failure during the February 4, 1976, Guatemala earthquake,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 11, 31.

Seismically induced liquefaction (the transformation of granular materials to a liquefied state because of increased pore-water pressure) caused ground failures in the Feb. 4, 1976, Guatemala earthquake. Failures occurred predominantly in areas of recent deposition such as deltas and stream channels, and around some small ponds and wet areas in the highlands. Water-laid saturated pumaceous sand deposits were highly susceptible to liquefaction. Lateral-spreading landslides with more than 9.6 m of horizontal displacement and 1 m of subsidence occurred on slopes as gentle as 3.2% on the youngest part of the delta in Lake Amatitlan (14 km south of Guatemala City), because of liquefaction of a shallow 1 m layer of pumice sand and gravel. Associated ground cracks and sand boils formed as much as several hundred meters from the lake shore and were generally oriented parallel to the lake shore or to river banks. Lateral spreading across these cracks destroyed some well-built reinforced brick houses that appeared to have suffered no direct shaking damage. At the Rio Panajachel delta on Lake Atitlan, 65 km west of Guatemala City, cracking and associated subsidence from lateral spreading caused moderate damage along the lake shore. In the swampy lower Motagua river valley, bank collapses were common and ground cracking and sand boils were noted as far as 100 meters from river banks. Liquefaction effects were also reported from Lake Izabal, from Puerto Cortez, Omoa, and the San Pedro Sula area in Honduras and from Lake Illopongo, El Salvador. The ground failures at Omoa affected houses built on sand dunes. There were ground cracks and damage to shoreline structures at a delta in Lake Illopongo about 240 km from the fault rupture.

● 8.5-6 Seed, H. B. et al., **Earthquake-induced liquefaction near Lake Amatitlan, Guatemala,** *UCB/EERC-79/27,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 1979, 34.

This report presents the results of a field and laboratory investigation of the extensive area of liquefaction which occurred at La Playa on the shore of Lake Amatitlan in the Guatemala earthquake of 1976. The investigation leads to the following conclusions. The soil in which liquefaction occurred was a layer of sand containing particles of pumice which occurred between depths of about 5 to 70 ft or more below the ground surface. It was covered by a surficial layer of lightweight pumice sand; and because of the pumice particles in the liquefied layer, its total unit weight had the relatively low value of about 90 lb/cu ft. In spite of the fact that the sand is somewhat lighter in weight than sand deposits which have liquefied in other earth-

● *See **Preface**, page v, for availability of publications marked with dot.*

quakes, its liquefaction characteristics are apparently influenced by the same factors as other sand deposits and its overall behavior is consistent with that exhibited by other sands. The penetration resistance of the sand at the boundary between liquefied and non-liquefied zones is in good accord with previously developed empirical correlations between liquefaction potential and the standardized penetration resistance at which liquefaction can just be expected to occur. The behavior of the sand in the liquefied and non-liquefied zones was consistent with experimental-analytical predictions of liquefaction potential based on the results of cyclic loading triaxial compression tests performed on undisturbed samples to evaluate the liquefaction characteristics of the sand and conventional procedures used in conjunction with this type of test data to evaluate liquefaction potential. The high degree of liquefaction at the La Playa site was probably caused in large measure by the lightweight nature of the pumiceous sands. A typical quartz sand at the same site with the same cyclic load characteristics as the sand containing pumice might well have remained stable in spite of the earthquake shaking. Consequently, lightweight noncohesive soils should be treated with special caution with regard to their liquefaction potential in seismically active regions. The results of the investigation provide an extremely useful case history in which field data on soil characteristics in an earthquake-liquefied zone and a non-liquefied zone can be correlated with field performance, thereby supplementing the limited number of available case studies of this type which can be used as a basis for predicting probable behavior at other sites. The results also tend to corroborate currently used procedures for evaluating liquefaction potential although, in the case of the laboratory test data, this clearly depends on the degree to which the in-situ properties of the soil are represented by the undisturbed samples extracted from the deposit. It is hoped that the results of the investigation will contribute to the available data base relating to earthquake-induced liquefaction and thereby to an improved predictive capability of this type of behavior in seismically active regions.

● *See **Preface**, page v, for availability of publications marked with dot.*

9. Earthquakes as Natural Disasters

9.1 Disaster Preparedness and Relief

● 9.1-1 Horiuchi, S. et al., **Study on the outbreak of fires caused by earthquakes: on the relationship between spread of fires in the inside of buildings and its factors** (in Japanese), *Transactions of the Architectural Institute of Japan, 280,* June 1979, 123–136.

To aid in the protection of large Japanese cities against fires caused by earthquakes, this paper examines the effects of building aspects on the spread of fires inside buildings. Statistics are compared for fires caused by earthquakes and fires caused by other means.

● 9.1-2 Okada, K. et al., **Presumption of human injury in case of earthquake's fire and consideration on its countermeasure (Part 1: structure of computer simulation model and its assumptions)** (in Japanese), *Transactions of the Architectural Institute of Japan, 275,* Jan. 1979, 141–148.

A practical simulation method is used to predict human injuries in fires caused by strong earthquakes. The model is based on a grid square system with the behavior of the evacuees in conformance with the spreading of the fires. Composed of 800 Fortran statements and requiring 8 min CPU time for one trial, the program prints results in map form. Because of its compactness, the system is easily applied to urban planning.

● 9.1-3 Howells, D. A., **Electricity supply systems in earthquake areas**, *Engineering Design for Earthquake Environments,* Paper No. C171/78, 17–22. (For a full bibliographic citation, see Abstract No. 1.2-2.)

Expressions are given for the seismic risk to a point and to a line in a region of uniform seismicity. These expressions are extended to assess the probability of simultaneous failure of two points and of two lines in parallel. Some comments are made on more general networks.

● 9.1-4 Hoshiya, M. and Ogasawara, Y., **Earthquake risk analysis of transportation networks and their optimum urgent planning**, *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 1, 1979, 165–183.

Once a disastrous earthquake has occurred, the first recovery action to be taken is usually to supply urgently needed goods and to assist persons in leaving the disaster area. A methodology is proposed for the optimum post-earthquake planning for communities in mountainous regions surrounded by the sea. A qualitative regression relevant to the hazard probabilities of the nodes and link elements of land and sea transportation networks is evaluated based on earthquake data. A case study is presented.

● 9.1-5 Fenves, S. J. and Law, K. H., **Expected flow in a transportation network**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 673–682.

This paper presents a method for estimating as a function of earthquake intensity the expected traffic flow rates, or the bounds on those rates, in a transportation network. A sample application of the method is presented.

● 9.1-6 Shinozuka, M. and Koike, T., **Seismic risk of underground lifeline systems resulting from fault movement**, *Proceedings of the 2nd U.S. National Conference on*

● *See* ***Preface,*** *page v, for availability of publications marked with dot.*

Earthquake Engineering, Earthquake Engineering Research Inst., Berkeley, California, 1979, 663–672.

A previously published seismic risk analysis procedure for underground lifeline systems is modified by consideration of differing local base-rock seismic intensities as a result of an earthquake triggered by a fault movement. This modification represents a particularly important improvement of the risk analysis procedure for the water supply network in Los Angeles because the entire area of Los Angeles is constantly threatened by possible major earthquakes originating from fault movements along the San Andreas and other faults.

● **9.1-7** **Final report on the earthquake relief in the Van region [Turkey]**, *Disasters*, 3, *1*, 1979, 17–18.

● **9.1-8** Leimena, S. L., **Disaster in Bali caused by earthquake 1976 (a report)**, *Disasters*, 3, *1*, 1979, 85–87.

● **9.1-9** Bolt, B. A., **Reassessing the earthquake hazard in California**, California Seismic Safety Commission, Sacramento, Apr. 1979, 11.

This report, dated Apr. 27, 1979, is a statement about the earthquake hazard in California, given by the author to a meeting of the California Seismic Safety Commission.

● **9.1-10** Katayama, T., Masui, Y. and Isoyama, R., **Fire-fighting, medical care and solid waste disposal after the Miyagiken-oki earthquake of June 12, 1978** (in Japanese), *Seisan-Kenkyu*, **31**, *8*, Aug. 1979, 10–18.

● **9.1-11** Ohta, Y. and Kagami, H., **Strategy for site planning of out-door refuge places in case of a large earthquake-algorithm for optimal disposition findings** (in Japanese), *Zisin, Journal of the Seismological Society of Japan*, **32**, *1*, Mar. 1979, 25–39.

In this paper, the linear programming method is employed to formulate an optimal-solution algorithm for use as the first step in establishing outdoor disaster relief centers for the protection of the public from fires caused by earthquakes. In the urban areas of Japan, where there are many overcrowded wooden houses, open spaces are indispensable for providing relief from such fires. In many cities, relief centers have been established; but, in most cases, the sizes and locations of the centers are inappropriate. In this paper, the appropriateness of such centers is evaluated from the standpoint of minimizing citizen traveling time. An optimal solution is obtained for an example city.

● **9.1-12** Hutman, S. and Dunne, R. G., eds., **Consensus report of the Task Force on Earthquake Prediction—City of Los Angeles**, Los Angeles, Oct. 1978, 47.

The recommendations of the task force as presented in the report to the mayor of Los Angeles follow. Los Angeles should prepare an Earthquake Prediction Response Plan and establish the appropriate coordination and organizational functions to enable a prompt and effective response to any prediction of an earthquake within the region. The plan should provide criteria and contingency plans for a wide range of potential responses geared to the specific time, location, magnitude and probability (or confidence level) of the prediction. This task force report provides suggestions and recommendations for criteria to be incorporated into the response plan. Ongoing and proposed programs of earthquake safety should be designed for appropriate augmentation or acceleration in the event of a significant earthquake prediction. A new emphasis should be placed on public information for earthquake preparedness: families, individuals, and neighborhoods will need to be self-sufficient for days and even weeks following a major earthquake, and special programs and materials should be prepared to encourage and assist in this preparation, which should be intensified following a significant earthquake prediction. Specialized programs and materials on earthquake preparedness should address the particular needs of children, the handicapped, and the elderly. State and Federal actions should be sought on several important issues: (a) enabling Federal disaster assistance to become available following the prediction of a major earthquake and in preparation for the anticipated disaster, (b) providing reliable earthquake insurance, either as a system of Federal earthquake insurance or as part of a Federal system of natural disaster insurance, (c) clarifying the legal authority and liability of the city for responsible actions taken in response to an earthquake prediction. The Earthquake Prediction Task Force should be reconvened by the mayor in two years (Oct. 1980) to review the progress in implementing the task force recommendations and to update the findings of the task force based on any changes in prediction technology, legislative action, available programs, or public concern.

● **9.1-13** Rogers, D. L., **Issues faced in programming Guatemala disaster rehabilitation assistance**, *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process*, n.p. [Guatemala, 1978], Vol. I, Paper No. 29, 15.

The Guatemalan earthquake of Feb. 4, 1976, attracted an enormous response from the international development assistance community to the needs caused by the disaster. Each organization had a particular set of priorities, goals, financial and human resources, past experiences, knowledge of disaster assistance, and working relationships within Guatemala which was applied to disaster needs as perceived by these organizations. On the other hand, the disaster-stricken population had its own perspectives of the effects of the disaster and of assistance priorities, in addition to complex pre-existing cultural, economic and social systems. This paper examines the major issues which arose from the intermingling of these two perspectives during programming and implementing of the post-earthquake disaster assistance activities. The ways the different organizations responded to this situation have left a greatly varied pattern of assistance programs, of victim/beneficiary satisfaction upon receiving aid, and of program effectiveness for the short- and medium-term processes of rehabilitation and change. Some of the experiences acquired in the Guatemala post-earthquake period probably can be applied to future disaster and development programming.

● **9.1-14** Brown, B. J., **Disaster preparedness and the United Nations: advance planning for disaster relief,** *Pergamon Policy Studies on Socio-Economic Development 34,* Pergamon Press, New York, 1979, 147.

This study examines the roles and relationships of a number of United Nations programs in the area of disaster relief and preparedness. The analysis and proposals are a practical reference guide for scholars and international program administrators. Data were obtained from archives and documents of the United Nations and several specialized agencies as well as from interviews with administrators of national disaster preparedness programs in developing countries and officials of the United Nations. The study is focused on the roles of several United Nations agencies and programs involved in disaster-related assistance, and the need for disaster preparedness in the most disaster-prone developing countries. There is a brief discussion of the relationship between disasters and development, in which the necessity of viewing natural disasters as a problem of development becomes clear.

● **9.1-15** Bolt, B. A. and Jahns, R. H., **California's earthquake hazard: a reassessment,** *Public Affairs Report,* **20,** *4,* Aug. 1979, 10.

● **9.1-16** **Disaster prevention and mitigation: a compendium of current knowledge. Volume 3: seismological aspects,** Office of the United Nations Disaster Relief Co-ordinator, United Nations, New York, 1978, 127.

This is the third volume in the series entitled "Disaster Prevention and Mitigation." The purpose of these publications is to provide the international community with a comprehensive review of existing knowledge of the causes and characteristics of natural phenomena and the preventive measures which may be taken to reduce or eliminate their impact on disaster-prone developing countries. The present volume deals mainly with ways of studying earthquakes and the measures which can be taken to mitigate or prevent their disastrous effects. It also discusses the different methods devised for this purpose and identifies subject areas in which research is still necessary.

● **9.1-17** **Disaster prevention and mitigation: a compendium of current knowledge. Volume 5: land use aspects,** Office of the United Nations Disaster Relief Co-ordinator, United Nations, New York, 1978, 69.

This is the fifth volume in the series entitled "Disaster Prevention and Mitigation." The purpose of these publications is to provide the international community with a comprehensive review of existing knowledge of the causes and characteristics of natural phenomena and the preventive measures which may be taken to reduce or eliminate their impact on disaster-prone developing countries. This publication examines the spatial aspects of disaster prevention, and, in particular, land use planning. It describes and evaluates measures designed to steer development away from hazardous areas and demonstrates how physical planning and especially land use control can contribute to reduce both disasters and the vulnerability of human settlements. The volume describes the aim and principles of comprehensive risk analysis, reviews land development and how it relates to the problem of disasters, and prescribes land use policies and measures which are most relevant to disaster prevention and mitigation, including legal controls, fiscal and financial incentives, and direct government action. A chapter has also been included on specific land use measures for the prevention and mitigation of flood and earthquake disasters.

● **9.1-18** **Disaster prevention and mitigation: a compendium of current knowledge. Volume 7: economic aspects,** Office of the United Nations Disaster Relief Co-ordinator, United Nations, New York, 1979, 73.

This is the seventh volume in the series entitled "Disaster Prevention and Mitigation." The purpose of these publications is to provide the international community with a comprehensive review of existing knowledge of the causes and characteristics of natural phenomena and the preventive measures which may be taken to reduce or eliminate their impact on disaster-prone developing countries. Very few systematic studies have so far been carried out on the economic aspects of disaster prevention and mitigation. An effort has been made in this volume to define methods for evaluating the direct and indirect damage caused by disasters and assessing the economic value of the various possible preventive measures, and to integrate the economic analysis of the risks and preventive measures within the process of physical planning and development, in particular by means of composite vulnerability analyses. Because this area is still relatively unexplored, much information is lacking, especially with regard to the real cost of disasters; in addition, therefore, the present volume endeavors to describe the various problems which exist and to make recommendations for remedying them.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 9.1-19 **Disaster prevention and mitigation: a compendium of current knowledge. Volume 10: public information aspects**, Office of the United Nations Disaster Relief Co-ordinator, United Nations, New York, 1979, 142.

This is the tenth volume in the series entitled "Disaster Prevention and Mitigation." The purpose of these publications is to provide the international community with a comprehensive review of existing knowledge of the causes and characteristics of natural phenomena and the preventive measures which may be taken to reduce or eliminate their impact on disaster-prone developing countries. This volume provides general and specialized knowledge and techniques which can be directly applied to the prevention and mitigation of disasters. It applies the results of several decades of social science research into the nature of human behavior and the behavior of institutions and organizations to disaster conditions. It takes into account the changing social structure of many countries brought about by rapid urbanization, rising literacy and new communication technologies, and suggests both traditional folk media and mass media approaches to problems. The core of the study treats public information policy and procedures. It examines the public information responsibility of various levels of government, as well as the responsibility of the public-at-large to implement measures of preparedness and prevention. The need for public education and the training of specialized personnel to carry out these tasks is made evident, as is the necessity for public information practitioners to apply and adapt these suggestions to suit their own national circumstance.

● 9.1-20 Tubbesing, S. K., ed., **Natural hazards data resources: uses and needs**, *Program on Technology, Environment and Man, Monograph* 27, Inst. of Behavioral Science, Univ. of Colorado, Boulder, 1979, 202.

Papers prepared for and presentations made during the Natural Hazards Data Resources Workshop, April 12-14, 1978, formed the basis for this monograph. It is out of discussions of the materials at the workshop that final recommendations have been developed to improve the usefulness and accessibility of hazards data resources. None of the papers presented at the workshop are individually abstracted in this volume of the *AJEE.*

9.2 Legal and Governmental Aspects

● 9.2-1 Wiggins, J. H., **Estimated building losses from U.S. earthquakes**, *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Inst., Berkeley, California, 1979, 253-262.

In 1975, the National Science Foundation sponsored a technological assessment of building losses from nine natural hazards: earthquakes, landslides, expansive soils, river floods, storm surges, tsunamis, hurricane winds, severe winds, and tornados. A technological assessment examines the secondary and higher order outcomes from the introduction of a technology or a policy which modifies a technology. As part of the process, the assessment was begun by first developing computerized national risk analysis models to provide for the introduction of various mitigations at various times that would mirror the effect of a specific policy. Then the usefulness of that policy as time continued could be traced.

This paper discusses the earthquake loss model and the effects of some of the mitigations introduced into the model. In this way, it is possible to assess the loss reduction potential of each earthquake mitigation policy. It is not claimed that the numbers cited are correct; instead the numbers are guides to be used by policymakers in making comparisons between other natural hazards and manmade hazards. Comparative judgments can also be made about the relative usefulness of various policies and each can be balanced against the costs of application and enforcement. No mitigation costs are addressed in this paper.

● 9.2-2 California, Seismic Safety Commission, **Evaluating the seismic hazard of state owned buildings**, *SSC 79-01*, Sacramento, 1979, 54.

A June 1977 California Seismic Safety Commission report proposed a methodology for use in evaluating the relative earthquake hazard of state-owned buildings. This methodology has since been tested to verify its validity so that comparable results can be obtained if it is decided to use the methodology as a basis for a comprehensive seismic evaluation of state-owned buildings. Presented are the conclusions and recommendations for implementation of the methodology, the details of the methodology, and an assessment and interpretation of the results.

● 9.2-3 Scott, S., **Policies for seismic safety: elements of a state governmental program**, Inst. of Governmental Studies, Univ. of California, Berkeley, 1979, 96.

This monograph discusses seismic hazards in California and the nation, compares eastern and western regions, reviews "acceptable risk," and outlines responsibilities for each level of government. Basic needs outlined in the report include regulation of the design and construction of buildings; dealing with critical facilities, unusually hazardous structures, and utility lifeline systems; use of planning and land-use control; providing for emergency preparedness and postearthquake recovery; and promoting research, information, and public awareness. Chapters summarizing California's experience discuss the earthquake safety of

● *See **Preface**, page v, for availability of publications marked with dot.*

public schools and hospitals, limiting construction in hazardous fault zones, mandating seismic safety elements in local plans, ensuring dam and reservoir safety, and providing for inundation mapping, evacuation planning, and freeway retrofitting for earthquake resistance. An extensive bibliography is included, and appendixes explain in layman's terms the Richter measurements of earthquake magnitude and the Mercalli intensity classification for earthquake damage.

● 9.2-4 Rivera E., H. M. and Serrano, J. A., **National emergency urban reconstruction plan (100 days plan)** (Plan nacional de reconstruccion urbana de emergencia (plan de los 100 dias), in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 15, 94.

This paper describes the criteria used and problems encountered by the authors in developing a national emergency plan. Included as appendixes are the plans for the capital city of Guatemala and for the interior portions of the country.

● 9.2-5 Laird, R. T. et al., **Quantitative land-capability analysis—selected examples from the San Francisco Bay region, California,** *Geological Survey Professional Paper 945,* U.S. Government Printing Office, Washington, D.C., 1979, 115.

The method of analyzing land capability described in this report estimates the costs of land utilization related to geologic characteristics and processes when existing use is converted to housing, commerce, and transportation. These costs are the total attributable to geologic conditions, regardless of who pays the costs. The costs include damage potential from natural hazards such as floods, landslides, or earthquakes; fees for special investigations, designs, or construction practices which are necessary to mitigate natural hazards or to remedy site deficiencies; and losses of potentially valuable natural resources such as sand and gravel. These costs are independent of any equity issues, and they are derived by assuming risk neutrality on the part of decisionmakers. Loss of life is probable for some natural hazards, but because costs attributable to life loss are difficult to evaluate, they are not considered in this analysis. Lower costs indicate a greater capability; that is, the land is relatively adaptable to the proposed new use.

Estimating cost, as a measure of capability, aids in planning, decisionmaking, and defining future research needs. This method of analyzing land capability makes it easy to compare the costs related to geologic constraints and compels the user to recognize and state his assumptions and to identify the information needed to define costs. The method is flexible so that, as more or better information becomes available, better estimates can be made. The method can also be extended to include other development costs, such as those for transportation and utility services.

Assessing capability begins by selecting the geologic processes or properties thought to influence costs for different activities on land. The geologic processes and properties that are judged most important in the part of the San Francisco Bay region analyzed in this report are grouped into resources (mineral, energy, water, or soil) and constraints. The most important constraints are flooding, erosion and sedimentation, and a variety of problems that are related to earthquakes, slope stability, and unsatisfactory foundation conditions. Information is collected and interpreted to describe and evaluate the relative importance of these processes and properties. Relative importance is expressed as the approximate cost related to each of eight representative land uses: (1) rural or agricultural, (2) semirural residential, (3) single-family residential, (4) multifamily residential, (5) regional shopping centers, (6) downtown commercial, (7) industrial, and (8) freeways. Because constraints and opportunities can be related in a common unit of measure (cost in dollars), the effects of different geologic processes and properties may be combined and summed. The total costs associated with all geologic problems for a specific use and a given area indicate the capability of that land to accommodate that use. Thus, capability maps can be produced for each land use when the sums of these costs are displayed by area on a map. Land-capability maps of this kind are a convenient means of displaying the data needed to evaluate alternatives and to make better decisions on land use. Together with other social and environmental information, the maps can be used by the planners, elected officials, and developers who share responsibility for land-use decisions, and they can provide a common basis for communication and for solving problems.

The Santa Clara valley south of San Francisco Bay is used to demonstrate the method because the area is undergoing development and has a variety of geologic hazards, constraints, and resources. The procedures and methods of analysis used in the demonstration area are described in detail in the text and are further amplified in sections at the end of the report so that planners in the San Francisco Bay region and elsewhere can modify and adapt this method of land-capability analysis to their own needs. Many problems encountered in evaluating land capability result from information deficiencies; much of the information needed is difficult to obtain, and for some subjects more fundamental research is needed. Throughout this report many of these information needs, such as cost estimates, maps, and data on recurrence intervals of hazards, are recognized. They are potential targets for research.

● 9.2-6 Scott, S. et al., **Goals and policies for earthquake safety in California,** *SSC 79-04,* California Seismic Safety Commission, Sacramento, May 1979, 76.

● *See* ***Preface***, *page v, for availability of publications marked with dot.*

The following chapters are included in the report: Chapter 1—Partnership for Seismic Safety; Chapter 2—Planning and Regulating Land Use; Chapter 3—Improving Building Design and Construction; Chapter 4—Critical Facilities and Utility Lifeline Systems: Location, Design, Construction and Operation; Chapter 5—Hazardous Buildings; Chapter 6—Improving Earthquake Preparedness and Response Capabilities; Chapter 7—Guiding Earthquake Recovery; Chapter 8—Promoting Earthquake Information, Education and Training; Chapter 9—Financing Seismic Safety; Chapter 10—Dealing with Earthquake Prediction; Chapter 11—Research Needs for Seismic Safety.

● 9.2-7 Steinbrugge, K. V. et al., **Issues for a national earthquake hazards reduction plan,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 37, 11.

This paper describes a United States national earthquake hazards reduction plan developed within the President's Office of Science and Technology Policy (OSTP). Two federal research-oriented agencies are expected to spend over $200,000,000 in a three-year period, and nearly all other federal agencies will be also involved to some extent. The national program's implementation plan provides for: (1) development of prediction techniques, and ensuring that a comprehensive response is made to the occurrence of an earthquake; (2) development of ways to include variations of seismic risk in making land-use decisions; (3) development of building standards, design criteria, and construction practices to achieve appropriate earthquake resistance for new and existing structures; (4) examination of alternatives for reducing earthquake hazards through governmentally financed construction, loans, loan guarantees, and licenses; (5) determination of the appropriate roles for insurance, loan programs, and public and private relief efforts in moderating the impacts of earthquakes; and (6) dissemination of information and knowledge to scientists, design professionals, construction executives, and the public to reduce vulnerability to earthquake hazards. As the first step towards achieving these goals, a Working Group identified 37 major policy issues which are discussed in the OSTP study "Earthquake Hazards Reduction: Issues for an Implementation Plan." The paper summarizes some of the important findings and recommendations given in that study.

● 9.2-8 Chavarria S., F., **Human settlements and their relation with the effects of the February 4th., 1976 earthquake in Guatemala** (Asentamientos humanos y su relacion con los efectos producidos por el terremoto del 4 de febrero de 1976 en Guatemala, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 18, 30.

This paper describes the housing requirements of Guatemala following the Feb. 4, 1976, earthquake and the efforts being made to meet these requirements. The author projects future housing needs and emphasizes the need for an integral study of seismic hazards in Guatemala to determine areas at high and low risk in order to best locate new housing developments.

● 9.2-9 Sloan, D., ed., **Seismic safety in Berkeley,** Univ. of California, Berkeley, June 1979, 200.

This report was prepared by participants in the Senior Seminar, Environmental Studies Group Major, at the Univ. of California, Berkeley. The report objective was to outline some of the seismic safety problems in Berkeley and to propose possible solutions to those problems. Included in the report are the following sections: Section I—Introduction and Earthquakes and Resulting Geologic Hazards; Section II—Berkeley's Emergency Response; Section III—Disruption and Recovery of Municipal Services; Section IV—Earthquake Preparedness on Campus; Section V—Preparing for a Large Earthquake in Berkeley. The last section contains chapters on the seismic safety of residences and industries in Berkeley and the awareness of seismic hazards by industrial plant managers in Emeryville.

● 9.2-10 Blair, M. L. and Spangle, W. E., **Seismic safety and land-use planning: selected examples from California. Basis for reduction of earthquake hazards, San Francisco Bay Region, California,** *U.S. Geological Survey Professional Paper 941-B,* U.S. Government Printing Office, Washington, D.C., 1979, 82.

This report is a product of the San Francisco Bay Region Environment and Resources Planning Study, an experimental program that was designed to facilitate the use of earth science information in regional planning and decisionmaking. The study was conducted from 1970 to 1976. Although the study was focused on the nine-county 74,400-square-mile San Francisco Bay region, it explored a problem common to all communities: how best to plan for orderly development and growth and yet conserve the natural resource base, ensure public health and safety, and minimize degradation of the natural and manmade environment.

The study has aided planners and decisionmakers by identifying important geologic and hydrologic problems that are related to growth and development, providing the earth science information needed to solve these problems, interpreting and publishing findings in forms understandable to and usable by nonscientists, establishing avenues of communication between scientists and users, and exploring different ways of applying earth science information in planning and decisionmaking. More than 100 reports and maps have been produced. These cover a wide range of topics, such as flood and earthquake hazards, unstable

● *See **Preface,** page v, for availability of publications marked with dot.*

slopes, engineering characteristics of hillside and lowland areas, mineral and water resources, solid and liquid waste disposal, erosion and sedimentation, and bay-water circulation patterns.

● **9.2-11** **Annual report to the Governor and the Legislature for 1978,** California Seismic Safety Commission, Sacramento, 1979, 24.

● **9.2-12** **The Field Act and California schools,** *SSC 79-02*, California Seismic Safety Commission, Sacramento, Mar. 1979, 77.

The Field Act prescribes a system of procedures and reviews to be followed during the design and construction of public school buildings for the protection of life and property. The provisions also apply to reconstruction, alterations, and additions which cost more than $20,000. Included are the text of the Field, Garrison, and Riley acts.

● **9.2-13** International Council on Monuments and Sites, Documentation Centre, **Catalog prepared by the International Committee Seism up to October 1979,** Paris, 1979, 13. (Catalog was distributed at the Seminar on the Protection of Monuments in Seismic Areas; for a bibliographic citation, see Abstract No. 1.2-46.)

● **9.2-14** California Seismic Safety Commission, Hazardous Buildings Committee, **Hazardous buildings: local programs to improve life safety,** *SSC 79-03*, Sacramento, Mar. 8, 1979, 170.

This report is designed to be readily usable by local governments in California because that is where the problem exists. The first section presents the overall conclusions and recommendations, and the main section contains a guide for organizing local programs to lessen the hazard. The appendixes contain a review of the committee's activities and reference materials designed to help those who must prepare abatement programs for hazardous buildings.

● **9.2-15** California Seismic Safety Commission, **Report on state agency programs for seismic safety,** Sacramento, June 4, 1979, 164.

This is a staff report presented to the California Seismic Safety Commission. The report fulfills two requests made by the commission: a request for budget information for fiscal year 1978-79 on state agency programs dealing with seismic safety, and a request for more detailed information regarding these state agencies and the operation of their programs. The report was also assembled with the additional thought of providing background material on the type and degree of state involvement in seismic safety for the commission's Earthquake Hazard Reduction and Prediction Systems Study (S.B. 1279). In this report, the programs operated by the state are divided into six major headings: disaster preparedness, earthquake information, scientific investigations, existing hazards, new construction, and policy.

● **9.2-16** California Seismic Safety Commission, **Report of the Task Committee of the Seismic Safety Commission on the Hospital Act of 1972,** *SSC 77-03*, Sacramento, May 1977, 69.

In 1975, the California Seismic Safety Commission established this committee to review the performance of the Hospital Act of 1972. The charge to the committee was to ascertain any problems, costs, and benefits in administration of the act and to report its findings and recommendations to the Seismic Safety Commission. The committee's task was divided into two phases. Phase one, to ascertain and report findings to the commission. Phase two, to make recommendations to the commission aimed at improving the act and its administration. The review includes any functional or administrative problems experienced by the Dept. of Health, the Office of the State Architect, and the Div. of Mines and Geology, as well as problems experienced by the users, including hospital associations, hospital administrators, and also by design professionals and the public. Preliminary data for the committee's review was gathered from the groups concerned with the Hospital Act and is presented in the appendix to this report.

● **9.2-17** California Seismic Safety Commission, Disaster Preparedness Committee, **Public official attitudes toward disaster preparedness in California,** *SSC 79-05*, Sacramento, 1979, 59.

This study addresses the identified lack of executive support for disaster preparedness, which was the major subject of a report presented to the California Seismic Safety Commission in Dec. 1977. The objective of this study is to identify means of motivating local and state government leaders to initiate the development of critical disaster response capabilities and to improve ongoing preparedness programs in their jurisdictions and agencies. The major concern is response to earthquakes, but it is recognized that most preparedness measures are applicable to other disasters as well. The Phase 1 portion of this study addresses local government perspectives while Phase 2 deals with the state government. Recommendations and means for implementing the findings of Phase 1 and Phase 2 will be the goal of the last portion of the study—Phase 3.

Attitudes probed in Phase 1 include: local officials' perception of hazards; local officials' perception of responsibility; evaluation of current disaster response capability; evaluation of possible incentives to improve response capability, such as earthquake prediction, funding, and public demand for better preparedness; ideas on types of assistance needed from other levels of government or research groups to improve local programs and approaches.

● *See **Preface**, page v, for availability of publications marked with dot.*

In Phase 2, key officials in the executive and legislative branches of state government were asked similar questions as those asked of local leaders in Phase 1. The methods and results of all surveys and personal interviews with local and state officials are contained in a technical supplement to this report which is available upon request from the Seismic Safety Commission office. Survey results are integrated into the text of this report.

9.3 Socio-Economic Aspects

● 9.3-1 Sauter F., F., **Damage prediction for earthquake insurance,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 99–108.

In this paper, the different methods for predicting damage caused by earthquakes are discussed and a simple method for calculating expected annual losses and insurance premium rates is proposed. A summary is presented of information on damage statistics in the form of average curves of damage ratios versus intensity for the most commonly used construction types.

● 9.3-2 Pate, M.-E., **Acceptance of a social cost for human safety: a normative approach,** *Proceedings of the 2nd U.S. National Conference on Earthquake Engineering,* Earthquake Engineering Research Inst., Berkeley, California, 1979, 477–486.

● 9.3-3 Wiggins (J.H.) Co., **Building losses from natural hazards: yesterday, today and tomorrow,** Redondo Beach, California [1978], 20.

● 9.3-4 Pate, M.-E., **Risk and public policy,** *Technical Report* 37, John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, July 1979, 53.

● 9.3-5 Friesema, H. P. et al., **Aftermath: communities after natural disasters,** Sage Publications, Beverly Hills, California, 1979, 183.

This book investigates whether communities suffer long-term economic losses and social dislocations as a result of natural disasters. Information is provided which can be used by the policy makers influencing our public and private responses to natural disasters. The book seeks to define the potential problems, not to provide their solutions. One way in which systematic impact analysis can be carried out is demonstrated. The merits and problems of several valuable approaches to performing systematic longitudinal impact studies are discussed.

● 9.3-6 Simpson-Housley, P., **Locus of control, repression-sensitization and perception of earthquake hazard,** *Natural Hazard Research Working Paper 36* [Inst. of Behavioral Science, Univ. of Colorado, Boulder], 1979, 39.

● 9.3-7 Pate, M.-E. and Shah, H. C., **Public policy issues: earthquake prediction,** *Bulletin of the Seismological Society of America,* **69,** *5,* Oct. 1979, 1533–1547.

This paper provides a method of cost-benefit analysis of earthquake prediction as a means of mitigation of earthquake effects. The research in earthquake prediction may or may not be successful and involves an initial cost. Earthquake prediction, if achieved, on the one hand provides society with information which allows it to take protective measures. On the other hand, each prediction involves the costs of those measures and the consequent disruption of economic life. The question is to assess the value of such information in a given state of prediction technology. The evaluation of a fault-monitoring program and its consequences for the public at the time of predictions is performed over a 50-year period. A rate of growth, a social rate of discount, and a rate of improvement over time of earthquake prediction techniques are assumed.

A model called "TREE" is developed; the model allows computation, for each year, of the expected value of the earthquake prediction information—expected costs minus expected benefits. The life component and the dollar component of the net result are kept separate throughout the evaluation. The final result is an expected cost per life saved through the earthquake prediction program over a 50-year time period. This allows comparison with the results of earthquake engineering and building codes. It also allows comparison with the results obtained in other public sectors involving risk mitigation—health and transportation, for example. A numerical example has been worked out for the case of the San Francisco Bay area; it gives a first approach to the results that can be expected from a prediction system with different assumptions on the success of research in that field.

● 9.3-8 Alexander, Jr., J. F., **Energy analysis and simulation of the Guatemala earthquake, 4 February 1976,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. II, Paper No. 50, 15.

This paper is an initial test of a general systems theory of the order-disorder processes of natural disasters. Energy circuit language is used to model the storage of strain energy in the Motagua fault system which was the source of the catastrophic pulse of energy in the Guatemala earthquake of Feb. 4, 1976. The destruction triggered by the distribution of earthquake energy to 16 randomly selected Guatemalan cities is also modeled. It was found that for each calorie of earthquake energy dissipated by a structure 1230 calories of potential energy was released by toppling adobe houses which created widespread human and social disorder.

● *See **Preface**, page v, for availability of publications marked with dot.*

● 9.3-9 Lensen, G. J., **Earthquake forecasting, public policy and earthquake forecasting,** *Proceedings of the Second South Pacific Regional Conference on Earthquake Engineering,* New Zealand National Society for Earthquake Engineering, Wellington, Vol. 2, 1979, 389–400.

The geodetic, geophysical, and seismological approaches to earthquake forecasting are summarized and illustrated with examples of precursory phenomena, which can be categorized into long-term, intermediate-term, short-term, and imminent. The results from at least two, but preferably more, disciplines are needed to reliably identify a precursory phase before a forecast can be made. The socioeconomic impact of earthquake forecasting on business and the community is discussed, and it is recommended that, at present, such forecasts not be made public. Instead, civil defense and related exercises should be held in several areas, including the "prone" area, to ensure that manpower is organized, equipment upgraded, and public awareness sharpened. The paper states that only when the public has gained confidence in the reliability of such forecasts and in the authorities concerned will public forecasting have a beneficial effect.

● 9.3-10 Berz, G., **Earthquake loss accumulation control,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 20, 7.

This paper discusses the increasing worldwide potential for catastrophic events, particularly from such natural hazards as earthquakes, windstorms, and floods, and also from the broad use of hazardous technologies. The assessment of this risk is a problem for many governments and for the international insurance industry. The two most important techniques of estimating the probable accumulation of losses—statistical analysis and simulation of single events—are discussed and examples are given. Specific problems encountered by the insurance industry are also shown. Since the observation periods in most countries are too short, only a worldwide comparison of loss experiences can provide an adequate basis for calculating probable losses resulting from a catastrophic event. This calculation would require a detailed subdivision of liabilities by geographical and engineering parameters. The economic effects of designing structures to withstand elementary forces, of repair of damaged structures, and of prediction and warning methods are discussed.

● 9.3-11 von Hoegen, M., **La Carolingia: a case of post-earthquake urban settlement** (La Carolingia: un caso de asentamiento urbano post-terremoto, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 19, 19.

As a consequence of the Feb. 4, 1976, Guatemala earthquake, several cases of spontaneous settlement by families who lost their homes occurred. This paper provides such data as the age characteristics, ethnic groups, legal status, migration, education, occupation, income, mortality, social participation, and demand for urban and social services of a post-earthquake settlement located in the western part of Guatemala City.

● 9.3-12 Bates, F. L. et al., **Rationale, design and methodology for a longitudinal and cross cultural study of the post impact phases of a major national disaster,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 34, 26.

This paper summarizes the theoretical and methodological aspects of a three-year study which focused on the long-range effects of the Feb. 4, 1976, Guatemala earthquake and the reconstruction process following the earthquake. A brief summary is presented of the techniques used to train interviewers and the procedures used to prepare the household interview schedule for field use.

● 9.3-13 Peralta, C. and Rodolfo, J., **Price evolution in building materials following the February 4, 1976 earthquake** (Evolucion del precio de los materiales de construccion despues del terremoto del 4 de febrero de 1976, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 23, 7.

The Feb. 4, 1976, earthquake affected several sectors of the economy of Guatemala, especially the housing industry and the urban infrastructure. The government of Guatemala issued decrees to control the prices of building materials in the face of urgent demands for such products. Inflation caused by an increase in monetary affluence, derived from international financial contributions sent to aid Guatemala, gave way to an increase in the demand for building materials. This paper discusses the effect of the earthquake on the cost of building materials.

● 9.3-14 Carmack, R. M., **Development and social effects of the Guatemalan earthquake,** *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 25, 12.

The effects of the Feb. 4, 1976, earthquake in the Occidente of Guatemala are studied in terms of social changes produced. The basic social structure of the area prior to the earthquake is summarized. Possible changes in the social structure as a result of the earthquake and subsequent aid programs are suggested. Earthquake aid is examined generally in terms of its similarity to other

● *See **Preface**, page v, for availability of publications marked with dot.*

developmental programs described by Manners. Many of the typical negative features suggested by Manners are found to occur in the case of earthquake reconstruction. The issue of development is then discussed in the context of the USAID lamina project, and reasons are given for the potentially negative impact of this project on development. Finally, some alternatives for long-term reconstruction are considered, and their implications for development discussed.

● **9.3-15** Cerezo R., A., **Essay on evaluation of general economic repercussions of the earthquake in one of the most affected areas** (Ensayo de evaluacion de las repercusiones economicas generales del terremoto en una de las areas mas afectadas, in Spanish), *Proceedings, International Symposium on the February 4th, 1976 Guatemalan Earthquake and the Reconstruction Process,* n.p. [Guatemala, 1978], Vol. I, Paper No. 26, 16.

The department of Chimaltenango, one of the most seriously damaged by the Feb. 4, 1976, Guatemala earthquake, is the subject of a review of the economic repercussions of the catastrophe. Damages were evaluated using the techniques of actuarial calculus and available statistics, especially demographic and vital statistics, as well as studies on family income and expenses. Besides material damage, the evaluation included personal damage as represented by death, incapacitation, an increase in the morbidity and mortality rates, and a deterioration in educational conditions, all of which have a negative influence on an economy.

Major results are as follows: (1) the economic impact in Chimaltenango of the damage, both material and human, is equivalent to the productive efforts of the total population of the department over a six-and-a-half-year period; (2) economic damages in this area are at least 12 times higher than the damages to the economy of the country viewed as a whole; and (3) the relative magnitude of damages is such that the population strata that suffered the losses will not be able to recover them, because they lack savings and the government is not in a condition to make up for such a deficiency.

● **9.3-16** Turner, R. H. et al., **Earthquake threat—the human response in southern California,** Inst. for Social Science Research, Univ. of California, Los Angeles, 1979, 152.

This report describes the results of a sample survey of 1450 adult residents of Los Angeles County, conducted in early 1977. The sample was designed to be representative of the entire county and to approximate a probability sample. The findings describe the public state of mind approximately one year after the first announcement of the southern California uplift.

● **9.3-17** Sauter F., F. and Shah, H. C., **Study on insurance against earthquakes** (Estudio de seguro contra terremoto, in Spanish), Franz Sauter & Assoc. Ltd., San Jose, Costa Rica, Sept. 1978, 390.

● **9.3-18** Wiggins, J. H., **The practical use of risk analysis: yesterday, today and tomorrow,** *Lifeline Earthquake Engineering–Buried Pipelines, Seismic Risk, and Instrumentation,* 207–218. (For a full bibliographic citation, see Abstract No. 1.2-16.)

This paper examines the use of techniques for risk analysis and gives three examples of how these techniques can be applied or their use avoided. One of the examples is of a Long Beach, California, ordinance aimed at the rehabilitation of existing hazardous buildings built before earthquake codes were adopted. For techniques of risk analysis to enjoy the respect they deserve, a standard set of "accounting principles," much the same as those for the accounting field, are recommended by the author. He further states that it may even be necessary to license or certify risk analysts in order to make risk analysis a useful art or science.

● **9.3-19** Turner, B. A., **Man-made disasters,** *Wykeham Science Series 53,* Wykeham Publications Ltd., London, and Crane, Russak & Co., Inc., New York, 1978, 254.

● **9.3-20** Lee, L. T., Chrostowski, J. D. and Eguchi, R. T., **Natural hazards: storm surge, riverine flooding, tsunami loss models,** J. H. Wiggins Co., Redondo Beach, California, 1978, 214. (NTIS Accession No. PB 294 682)

This report presents the details of the methodology and results of a study of the risk to structures in the United States from riverine flood, storm surge, and tsunamis. The hazard, exposure, and vulnerability models developed during the study are described in detail for each of the three hazards. Descriptions of the damage algorithms, the loss computation procedures, and the projected average annual losses through the year 2000 are also presented. For riverine flood, the baseline was taken in two ways: no land use control or with the current projections in land use control. Riverine flood appears to diminish in severity by the year 2000 if current trends in land use control and protection measures are continued. Nevertheless, the annual losses could be further reduced by about 20 percent if a program to implement flood-proofing of flood-prone structures was begun. Several mitigation policies were tested for storm surge losses. The baseline model showed storm surge structural damage increasing from 440 million dollars in 1970 to 1200 million dollars in 2000 as a result of developmental growth on coastal flood plains. Two configurations for tsunamis affecting the coastal communities in the Pacific Basin were investigated: present conditions and growth projections with no mitigation to reduce damage and restricting new growth on the 50- or 100-year

● *See **Preface**, page v, for availability of publications marked with dot.*

flood plain. For the baseline model, the average annual losses increased from 15 million dollars in 1970 to 28 million dollars in 2000.

● 9.3-21 Hirschberg, J. C., Gordon, P. and Petak, W. J., **Natural hazards: socio-economic impact assessment model**, J. H. Wiggins Co., Redondo Beach, California, July 1978, 320. (NTIS Accession No. PB 294 861)

The study reports on models that were used to measure the expected losses that could be associated with a variety of natural disasters. Data sources and data manipulations that were required to make the models operational are reviewed. The tenets of cost benefit analysis were adopted as a framework. The models are built on the premise that the probabilities of various disasters and the intensities of these disasters can be jointly predicted for future time periods for small regions. Values-at-risk are to be multiplied by the probabilities of each loss, for all levels of loss, with the results summed to yield expected loss. The wealth-at-risk, once determined, had to be projected into the future using a reasonable rate of wealth growth. At the same time, future losses had to be discounted to the present using similar rates. Secondary economic effects play a role on the demand side as well as on the supply side. It is presumed that the loss of productive capacity has an effect throughout the regional economy because of a removal of demand. The study reports on detailed multiplier effects which are computed from a set of regional and interregional input-output tables. On the supply side, it is suggested that many sellers will have to expand the range of their marketing. The study also reports on tests and applications of the methodology, sensitivity tests, tests on known historical disaster events, and actual cost-benefit analysis of selected mitigation measures.

● 9.3-22 Wiggins, J. H., Slosson, J. E. and Krohn, J. P., **Natural hazards: earthquake, landslide, expansive soil loss models**, J. H. Wiggins Co., Redondo Beach, California, Dec. 1978, 166. (NTIS Accession No. PB 294 686)

Natural hazards generally associated with earth movement are considered, namely, earthquake, landslide, and expansive soil. Each hazard was modeled with regard to national and sudden loss projections. Regarding the earthquake hazard, it is estimated that the annualized loss to the nation is about $650 million in damage. Expansive soils, although not dramatic in nature, caused the 1970 building wealth in 1970 dollars to experience losses on the order of $1.1 billion. Landslide caused on the order of $200 million in annualized losses to the 1970 building population at risk in terms of 1970 dollars. From the standpoint of sudden losses (a 100-year event), earthquake dominates the scene for all earth-related hazards. No sudden loss scenarios were computed for landslide and expansive soil losses since their statistical extremes are not very severe. Mitigations were applied to the theoretical national loss and earth hazard models. It was determined that, if the most effective mitigations were invoked beginning in the year 1981, approximately 24 percent of the annual loss projected by the year 2000 could be saved. Of all the natural hazards examined, it was determined that earthquake is by far the most extreme type of hazard and also affords the greatest possibility of sudden loss reduction should adequate warning be given and consequent appropriate actions taken to reduce the risk.

● 9.3-23 Osterling, J. P., **The 1970 Peruvian disaster and the spontaneous relocation of some of its victims: Ancashino peasant migrants in Huayopampa**, *Mass Emergencies*, 4, 2, Nov. 1979, 117-120.

On May 31, 1970, a major earthquake occurred in Peru, affecting an area of approximately 64,000 km^2. During the earthquake, as many as 70,000 persons lost their lives and at least 150,000 were injured. Landslides buried towns and settlements and damage amounted to hundreds of millions of dollars (U.S.). This article discusses how the catastrophe contributed to the emigration of peasants from the highland region of Ancash, which was the area most destroyed by the earthquake, to Huayopampa, a relatively small and obscure rural community about four hours' drive north of Lima. In order to enhance their prospects for establishing roots in the area and to find an immediate solution to their economic problems caused by the earthquake, the Ancash migrants have endeavored to capitalize on an economic boom in Huayopampa.

● 9.3-24 Barbina, G., **The Friuli earthquake as an agent of social change in a rural area**, *Mass Emergencies*, 4, 2, Nov. 1979, 145-149.

On the basis of a preliminary analysis of field data, the author examines some of the social and economic changes brought about by the Friuli, Italy, earthquakes of May and Sept. 1976.

● 9.3-25 Reitherman, R., **Earthquake insurance in California**, Center for Planning and Development Research, Univ. of California, Berkeley, 1978, 65.

● 9.3-26 Petak, W. J., Atkisson, A. A. and Gleye, P. H., **Natural hazards: a public policy assessment**, J. H. Wiggins Co., Redondo Beach, California, Dec. 1978, 543. (NTIS Accession No. PB 297 361)

This study concerns the (1) identification and description of the characteristics, geographic distribution, and potential effects of nine hazardous natural events within the United States; (2) assessment of the vulnerability of several classes of buildings, and their occupants, to each hazard; (3) identification and measurement of the major primary, secondary, and higher order effects expected to be associated with the exposure, by major geographic area, of

● *See **Preface**, page v, for availability of publications marked with dot.*

buildings and their occupants to these hazardous natural events; (4) identification and explication of the major candidate public problems which are associated with these effects; (5) identification of the costs and characteristics of the major types of technologies appropriate for mitigating the effects induced by exposure of buildings and their occupants to each of the nine natural hazards; (6) identification and description of the major types of public policies which may induce the application of hazard-mitigating technologies; (7) estimation of the economic costs and other effects associated with the use of selected technologies to mitigate the effects of these hazards; (8) identification of the major effects and candidate public problems which might be generated by the use of selected technologies in mitigating the effects; and (9) identification and evaluation of the major problem-solving strategies and public policies which are relevant to the problems identified.

● 9.3-27 **A program of studies on the socioeconomic effects of earthquake predictions,** Committee on Socioeconomic Effects of Earthquake Predictions, National Research Council, National Academy of Sciences, Washington, D.C., 1978, 162.

The purpose of this report is to point out the possible consequences arising from earthquake predictions and to suggest the research necessary to anticipate and deal with them. This report is part of a long-standing program of the National Academy of Sciences–National Research Council concerning natural and man-made hazards and disasters. In particular, it is an outgrowth of the report on *Earthquake Prediction and Public Policy*, prepared by the NRC Panel on the Public Policy Implications of Earthquake Prediction, Advisory Committee on Emergency Planning, published by the Academy in 1975.

The chapters of the present report are entitled: 1. Introduction; 2. Conceptual Framework; 3. Individuals, Households, and Social Groups; 4. Economic Consequences of Earthquake Predictions: Business Firms and the Regional Economy; 5. Government; 6. Studies of Legal Problems in Earthquake Prediction; 7. Studies of the Generation and Dissemination of Earthquake Predictions; 8. Research Strategies and Priorities.

● 9.3-28 Australia Technical Committee upon Technical Aspects of a National Scheme for Natural Disaster Insurance, **A natural disaster insurance scheme for Australia** [Canberra], Feb. 1978, 262.

● 9.3-29 Johnson, G. W. and Nye, R. L., eds., **Environmental hazards and community response: the Santa Barbara experience,** *Public History Monograph* 2, Graduate Program in Public Historical Studies, Univ. of California, Santa Barbara, 1979, 393.

● *See **Preface,** page v, for availability of publications marked with dot.*

List of Titles

Numbers used are abstract numbers.

SECTION 1. General Topics and Conference Proceedings

1.1 General

1.2 Proceedings of Conferences

SECTION 2. Selected Topics in Seismology

2.1 Seismic Geology

2.2 Wave Propagation

2.3 Source Mechanisms

2.4 Seismicity, Seismic Regionalization, Earthquake Risk, Statistics and Probability Analysis

2.5 Studies of Specific Earthquakes

2.6 Seismic Water Waves

2.7 Artificially Generated Ground Motions or Seismic Events

2.8 Earthquake Prediction

2.9 Special Topics

SECTION 3. Engineering Seismology

3.1 General

3.2 Strong Motion Records, Interpretation, Spectra

3.3 Artificial and Simulated Earthquake Records

3.4 Seismic Zoning

3.5 Influence of Geology and Soils on Ground Motion

3.6 Seismic Site Surveys

SECTION 4. Strong Motion Seismometry

4.1 Instrumentation

4.2 Regional Data Collection Systems

SECTION 5. Dynamics of Soils, Rocks and Foundations

5.1 General

5.2 Dynamic Properties of Soils, Rocks and Foundations

5.3 Dynamic Behavior of Soils and Rocks

6.3 Dynamic Properties of Linear Structures

6.4 Deterministic Dynamic Behavior of Linear Structures

6.5 Nondeterministic Dynamic Behavior of Linear Structures

6.6 Deterministic Dynamic Behavior of Nonlinear Structures

6.7 Nondeterministic Dynamic Behavior of Nonlinear Structures

6.8 Soil-Structure Interaction

6.9 Fluid-Structure Interaction

6.10 Vibration Measurements on Full Scale Structures

6.11 Experimental Facilities and Investigations

6.12 Deterministic Methods of Dynamic Analysis

6.13 Nondeterministic Methods of Dynamic Analysis

SECTION 7. Earthquake-Resistant Design and Construction and Hazard Reduction

7.1 General

7.2 Building Codes

7.3 Design and Construction of Buildings

7.4 Design and Construction of Nuclear Facilities

7.5 Design and Construction of Miscellaneous Structures

7.6 Design and Construction of Foundations, Piles and Retaining Walls

7.7 Design and Construction of Soil and Rock Structures

SECTION 8. Earthquake Effects

8.1 General

8.2 Studies of Specific Earthquakes

8.3 Effects on Buildings

8.4 Effects on Miscellaneous Structures and Systems

8.5 Effects and Near Surface Geology

SECTION 9. Earthquakes as Natural Disasters

9.1 Disaster Preparedness and Relief

9.2 Legal and Governmental Aspects

9.3 Socio-Economic Aspects

Author Index

Numbers used are abstract numbers.

Preceding page blank

Subject Index

Numbers used are abstract numbers. Items in **boldface** refer to sections or subsections of the Journal. Items in *italics* refer to other references in the Subject Index.