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Abstract Journal in Earthquake Engineering

Volume 8: 1978 Literature
December 1979
Earthquake Engineering Research Center
University of California, Berkeley

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NATIONAL SCIENCE FOUNDATION

Abstract Journal in Earthquake Engineering

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Earthquake Engineering Research Center
University of California, Berkeley

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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 86 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 8.

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 7. 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.
IPC House
32 High Street
Guildford, Surrey GU1 3EW, England

Asian Building and Construction
1913 Hanglung Centre
Causeway Bay
Hong Kong

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

Bollettino di Geofisica
Osservatorio Geofisico Sperimentale
34123 Trieste, 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**
P.O. Box 826
Berkeley, California 94701

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)
Science House
Gloucester & Essex Streets
Sydney, N.S.W., 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

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 and 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
Amsterdam, The Netherlands

*Engineering Structures**
IPC Science and Technology Press Ltd.
Westbury House, Bury Street
Guildford, Surrey GU2 5AW, England

*EOS Transactions of the American Geophysical Union**
American Geophysical Union
1909 K Street, N.W.
Washington, D.C. 20006

*Experimental Mechanics**
Society for Experimental Stress Analysis
21 Bridge Square
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
26-34 Old Street
London ECIP 1JH, England

*Geothermics**
Istituto Internazionale per le Ricerche Geotermiche
Lungarno Pacinotti 55
56100 Pisa, Italy

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 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

*Iranian Journal of Science and Technology**
School of Engineering
Pahlavi University
Shiraz, Iran

*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
Redford Station
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
1909 K Street, N.W.
Washington, D.C. 20006

*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
Northgate Avenue, Bury St. Edmunds
Suffolk IP32 6BW, England

*Journal of Physics of the Earth**
University of Tokyo Press
c/o Center for Academic Publications
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 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**
American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

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

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
Amsterdam, The Netherlands

*Physics of the Solid Earth**
American Geophysical Union
1909 K Street, N.W.
Washington, D.C. 20006

*Proceedings**
The Institution of Civil Engineers
Great George Street
London S.W. 1, 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

*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.
3F Kohri Building
6-11-17, Roppongi
Minato-ku
Tokyo 106, Japan

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

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

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** Lee, K. L. *et al.*, eds., **Research needs and priorities for geotechnical earthquake engineering applications,** U.S. National Bureau of Standards [Washington, D.C.], 1978, 148.

A two-day workshop was held at the Univ. of Texas, Austin, June 2–3, 1977, for the purpose of synthesizing professional opinions concerning research needs and priorities in geotechnical earthquake engineering. Seventy-two participants from the U.S., Canada, and Mexico attended. The workshop was composed of a series of group discussions of small numbers of experts on the following seven topic areas: (1) dynamic soil properties and measurement techniques in the laboratory; (2) dynamic soil properties and measurement techniques in the field; (3) analytical procedures and mathematical modeling; (4) design earthquakes, ground motion, and surface faulting; (5) assessment of the seismic stability of soil; (6) soil-structure interaction; and (7) experimental modeling and simulation. This report summarizes and synthesizes opinions expressed in the group discussions. The authors hope that this report will serve as a guide to funding agencies and to researchers of the important topics needing special study in the near future.

● **1.1-2** Morton, D. R., comp., **A selected, partially annotated bibliography of recent (1976-1977) natural hazards publications,** Natural Hazards Research and Applications Information Center, Univ. of Colorado, Boulder, Colorado, 1978, 62.

This is a partially annotated bibliography of recent publications concerned with the reduction of losses caused by natural hazards and disasters. The entries are arranged by general subject classification, and at the end of the bibliography there are subject and author indexes.

● **1.1-3** Habercom, Jr., G. E., ed., **Earthquake engineering: buildings, bridges, dams, and related structures. Vol. 3. Oct. 1977–Aug. 1978: a bibliography with abstracts,** National Technical Information Service, Springfield, Virginia, Sept. 1978, 112. (NTIS Accession No. PS-78/0942)

This updated bibliography contains 112 abstracts, all of which are new entries to the previous edition. Seismic phenomena related to buildings, bridges, dams, and other structures are investigated. Damage assessment is made and design inadequacies are revealed. Suggestions for structural improvements for dynamic response are presented. Abstracts on site selection and earthquake-proofing for atomic power plants are included.

● **1.1-4** **European Association for Earthquake Engineering Working Group Reports,** *Bulletin of the European Association for Earthquake Engineering,* 4, *1,* Sept. 1978, 89.

This edition of the *Bulletin of the European Association for Earthquake Engineering* contains seven reports of EAEE working groups and some EAEE general documents. The working group reports, none of which are abstracted individually in this volume of the *AJEE,* are listed below. *On unification of codes for structural design in seismic areas,* Polyakov, S. V. and Kilimnik, L. Sh.—*Progress report of the EAEE working group on strong-motion studies for the period 1975–1978 (part I),* Ambraseys, N. N. and Moinfar, A. A.—*Preliminary analysis of European strong-motion data 1965–1978 (part II),* Ambraseys, N. N.—*Design criteria for low-cost housing in the Yugoslav practice,* Velkov, M. and Simeonov, B.—*Design and construction of reinforced concrete precast buildings in seismic regions (problems and activity),* Sachanski, S.—*Cost-benefit analysis in earthquake engineering,* Grandori, G.—*Rural dwellings in earthquake areas in Turkey,* Yarar, R.

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

1.2 Proceedings of Conferences

1.2-1 Committee on Coastal Engineering of the Japan Society of Civil Engineers, **A look at coastal engineering study in Japan,** *Journal of the Waterway, Port, Coastal and Ocean Division, ASCE,* **104,** *WW1,* Proc. Paper 13532, Feb. 1978, 19–38.

Papers presented at the 1976 National Conference on Coastal Engineering in Japan are reviewed. This conference has been held annually since 1954. The paper topics include the following: waves (20 papers); coastal sediment problems and beach processes (26 papers); coastal and offshore structures (35 papers); tsunami and harbor oscillations (10 papers); environmental problems (16 papers); and miscellaneous problems (5 papers).

● 1.2-2 **Proceedings of the Seminar on the Social and Economic Effects of Earthquake Prediction, Wellington, 12 October, 1977,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *1,* Mar. 1978, 1–49.

The seminar was held in Wellington, New Zealand, on Oct. 12, 1977. The Dept. of Univ. Extension at Victoria Univ. and the New Zealand National Society for Earthquake Engineering organized this seminar to bring together people qualified to speak on the social and economic effects of earthquake prediction. Paper titles and authors for the 14 presentations given at the seminar are listed below. The papers are not abstracted in this volume of the *AJEE. Earthquake prediction,* Evison, F. F.—*The political and legal effects,* Marshall, J.—*The economic issues,* Thompson, G.—*Civil defence aspects,* Holloway, R. H. F.—*The social implications of earthquake predictions and warnings on and for organisations,* Britton, N. R.—*The effect of earthquake prediction on earthquake insurance in New Zealand,* Hellberg, M.—*Role of the media in earthquake prediction,* Robson, M.—*Mitigation of danger to property,* Strachan, C. M.—*The roles of central and local government in pre-disaster planning,* O'Dea, P.—*The police role,* Mitchell, R. S.—*The effects of earthquake prediction on the Ministry of Works and Development,* Stirrat, A. G.—*The implications of earthquake prediction for the New Zealand Electricity Department,* O'Brien, M. T.—*The role of local bodies,* Fowler, M.—*Central government and earthquake prediction,* Roberts, J. L.

● 1.2-3 Ang, A. H.-S., ed., *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, 1978, 429.

The symposium was held at the Philippine International Convention Center in Manila, Philippines, from September 26-30, 1977. The sponsors of the symposium were the Philippine National Science Development Board, the Univ. of the Philippines System, and the U.S. National Science Foundation. The symposium consisted of a technical conference and a research workshop. Papers presented at the technical conference are included in the Proceedings. Sixteen papers pertinent to earthquake engineering are abstracted in this volume of the *AJEE.* The following are the titles and authors' names.

Risk and safety analysis in design for natural hazards protection, Ang, A. H.-S. and Wen, Y. K.—*Risk and decision in engineering for natural hazards protection,* Vanmarcke, E. H.—*Earthquake risk analysis for Metro Manila,* Su, S. S.—*Risk analysis of underground lifeline network systems,* Shinozuka, M., Takada, S. and Kawakami, H.—*Statistical nature of earthquake ground motions and structural response,* Penzien, J.—*Stochastic process models of strong earthquake motions for inelastic structural response,* Kameda, H.—*Vulnerability analysis of natural disaster risks for the Metro Manila area,* von Einsiedel, N.—*Seismic risk analysis including attenuation uncertainty,* Der Kiureghian, A.—*Probabilistic solution to hysteretic systems subjected to earthquakes,* Karasudhi, P., Wu, C.-C. and Takemiya, H.—*Seismic analysis of soil-building interaction systems,* Karasudhi, P., Balendra, T. and Lee, S.-L.—*Seismic response and reliability of mechanical systems—effects of uncertainty of ground motions,* Shibata, H., Shigeta, T. and Sone, A.—*Current trends in the seismic analysis and design of structures and facilities,* Hall, W. J.—*Development of earthquake resistant design method employing ultimate capacity concept,* Aoyama, H.—*Seismic design of masonry structures,* Priestley, M. J. N.—*The prevention and control of landslides,* Koh, S. L. and Chen, W.-F.—*Some observations on the damages resulting from the Mindanao earthquake of August 17, 1976,* Hizon, A. O.

● 1.2-4 **Stability of structures under static and dynamic loads,** Proceedings of International Colloquium, Washington, D.C., May 17-19, 1977, American Society of Civil Engineers, New York, 1977, 812.

The colloquium was held in Washington, D.C., from May 17-19, 1977. The National Science Foundation sponsored the colloquium, and it was organized by the Structural Stability Research Council, the European Convention for Construction Steelwork, the International Assn. for Bridge and Structural Engineering, and the Column Research Committee of Japan. The subject matters covered in the papers include structural dynamics, frames, tubes and shells, plates and girders, and beams. Only the following papers are abstracted in this volume of the *AJEE: Seismic design in Japan,* Kato, B.—*Seismic design of mixed steel concrete structures in Japan,* Wakabayashi, M.—*Effects of P-Δ moments and rotatory inertias on the behavior of building structures,* Karadogan, H. F.

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

● **1.2-5 AGU Midwest Meeting Report, abstracts,** *EOS, Transactions of the American Geophysical Union,* **59,** *4,* Apr. 1978, 220-231.

The third annual Midwest Meeting of the American Geophysical Union was held at Purdue University from Sept. 26-28, 1977. In this issue of *EOS*, abstracts of the papers are presented. The following titles, authors' names, and paper numbers (in parentheses) refer to those abstracts which pertain to earthquake engineering. These abstracts are not included in this volume of the *AJEE*.

A global tectonic activity map, Lowman, Jr., P. D. (T1)—*The seismicity of Indiana described by return periods of earthquake intensities,* Blakely, R. F. and Varma, M. M. (S1)—*A study to determine the causes of eastern Kansas earthquakes,* Steeples, D. W. and Wilson, F. W. (S2)—*The Celina, Ohio earthquake: June 17, 1977,* Mauk, F. J. (S3)—*Earthquakes in the central Mississippi valley,* Nuttli, O. W. (S5).

● **1.2-6 AGU Pacific Northwest Meeting Report, abstracts,** *EOS, Transactions of the American Geophysical Union,* **59,** *4,* Apr. 1978, 232-238.

The twenty-fourth annual meeting of the American Geophysical Union's Pacific Northwest Region was held at Portland State University, Portland, Oregon, on Sept. 29 and 30, 1977. In this issue of *EOS*, the program and abstracts of the papers are presented. The following titles, authors' names, and paper numbers (in parentheses) refer to those abstracts which pertain to earthquake engineering. These abstracts are not included in this volume of the *AJEE*.

A comparison of near, intermediate, and far field spectra for earthquake type sources, Malone, S. D., Pavlis, G. and Blacic, J. D.—*Seismicity offshore western Canada,* Hyndman, R. D., Rogers, G. C. and Lee, K.

● **1.2-7 Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,** *Organisation for Economic Co-operation and Development, Nuclear Energy Agency, Committee on the Safety of Nuclear Installations, Report 28,* Comitato Nazionale Energia Nucleare, Rome, May 1978, 3 vols., 881.

The meeting was held in Rome from Oct. 11-13, 1977. The co-sponsors were the Committee on the Safety of Nuclear Installations of the Organisation for Economic Co-operation and Development Nuclear Energy Agency and the Italian Comitato Nazionale per l'Energia Nucleare, in cooperation with the Italian Ente Nazionale per l'Energia Elettrica. The papers are presented in three volumes and are written in English or French. In addition to technical papers, Volume III contains: "Final Panel: Conclusions and Recommendations of the Specialist Meeting"; Appendix 1—Conclusions and Recommendations of the Specialist Meeting of the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations; Appendix 2—List of Participants; and Appendix 3—Programme of the Meeting and List of Programme Committee Members. All papers are abstracted or cited in this volume of the *AJEE*. The paper titles and authors' names follow.

Volume I: Introductory Session—The 1976 Friuli Earthquake: *Presentation of the Friuli earthquake,* Giuliani, P.—*The broad geodynamical frame of Friulian seismicity,* Ogniben, L.

Session I.a—Geotectonic, Geophysical and Seismological Aspects: Geotectonics: *The Friuli earthquake (Italy, 6 May 1976) in its seismotectonic context* (in French), Weber, C. and Courtot, P.—*Geological and morphological phenomena caused by high seismicity as a natural source of information on recent seismicity,* Carraro, F. and Polino, R.—*Influence of the local surface strata of the earth crust on the effects of the May 6, 1976 Friuli earthquake,* Caloi, P. and Migani, M.—*Ground cracks caused by the Friuli earthquake, 1976, from M. Cuarnan and Tremugna Valley,* Martinis, B. and Cavallin, A.—*Seismotectonic investigations in northeastern Italy,* Benvegnu, F. *et al.*

Session I.b—Geotectonic, Geophysical and Seismological Aspects: Geophysics and Seismology: *Macroseismic observations of the Friuli earthquake of May 6, 1976,* Gutdeutsch, R.—*Contribution to the near field study of the aftershocks of the earthquakes on May 6th and September 15th 1976 in Friuli (Italy)* (in French), Wittlinger, G., Haessler, H. and Hoang Trong, P.—*Seismicity of the Friuli area recorded by a French seismic network from May to October 1976* (in French), Delhaye, A., Massinon, B. and Rigaud, J. F.—*Note on fault plane solutions relative to the major shocks and some aftershocks of the Friuli area during May to September 1976* (in French), Delhaye, A. *et al.*—*Space-time distribution of the 1976 Friuli earthquake shocks,* Cagnetti, V. and Console, R.

Volume II: Session II—Instrumentation and Data Processing: *A telemetered 7 stations seismic-network for near field study* (in French), Wittlinger, G., Holl, J. M. and Ball, G.—*Experience on the performance of CNEN seismic instrumentation in Friuli,* Cervellati, R.—*Calibration of strong-motion accelerometers Kinemetrics SMA-1,* Cervellati, R. and Rienzo, G.—*Strong-motion records of Friuli earthquake 1976,* Mihailov, V.—*Analysis of strong motion records of the Friuli earthquake obtained in Yugoslavia,* Petrovski, D. and Naumovski, N.—*Study of the aftershocks of the May 6, 1976 Friuli earthquake* (in French), Barbreau, A. *et al.*—*Strong motion records of Friuli earthquake,* Basili, M. *et al.*—*Estimate of seismic moment and other seismic parameters of some 1976 Friuli earthquakes,* Basili, M. *et al.*—*Seismic evolution of the Friuli earthquake (1976-1977),* Finetti, I. *et al.*

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

Session III—Soil Behaviour and Its Interaction with Structures: *A geophysical assessment of near-field ground motion and the implications for the design of nuclear installations,* Bernreuter, D. L.—*The Friuli 1976 earthquake considered as a "near source earthquake." presentation and discussion of the surface recordings,* Muzzi, F. and Vallini, S.—*Analysis of rock motion accelerograms recorded at surface and underground during the 1976 Friuli seismic period,* Berardi, R., Capozza, F. and Zonetti, L.—*Analysis of the dynamic response of a soil deposit in locality "Ca'Dant" (Cornino-Forgaria),* Muzzi, F. and Pugliese, A.—*Soil-structure interaction analysis of the building "Condominio Giardini" in Maiano,* Berardi, R. *et al.*

Volume III: Session IV—Behaviour of Structures and Utilities: *Elastoplastic response spectra of the Friuli earthquakes. effects of the decay of the mechanical properties in R/C structures taking into account the P-Δ effect,* Braga, F. and Parducci, A.—*On the influence of the horizontal ground acceleration components acting contemporaneously on a dissymmetric structure,* Brancaleoni, F., Gavarini, C. and Petrangeli, M. P.—*Behaviour of damaged buildings during renewed earthquakes,* Heimgartner, E. and Glauser, E. C.—*Earthquake response analysis of the new civil hospital in Tolmezzo, Friuli,* Scelfo, A., Pino, G. and Schembri, B.—*An investigation on the behavior of an instrumented multistory building in Maiano during the Friuli earthquake,* Berardi, R. and Sano, T.—*The Friuli earthquake as a test of the Spanish building code* (abstract only), Lopez Arroyo, A. and Villacanas, J.

Session V—Seismic Risk Evaluation: *The distribution of the faults and the maximum magnitude of a seismic region,* Caputo, M.—*A stochastic analysis of 1976 Friuli earthquake seismic data,* Basili, A. *et al.*—*Tilt variations and seismicity that preceded the strong Friuli earthquake of May 6th, 1976,* Biagi, P. F. *et al.*—*A re-appraisal of the Friuli 1976 & Romanian 1977 earthquakes,* Ambraseys, N. N.—*Preliminary seismic risk assessment for northwestern Turkey,* Gurpinar, A. and Gulkan, P.—*Seismic zoning and nuclear power plants,* Roussopoulos, A.—*Considerations on the safety of possible nuclear installations in northeastern Italy in relation to local seismotectonics,* Benvegnu, F. *et al.*

● 1.2-8 Sherif, M. A., chmn., **Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,** National Science Foundation *et al.*, San Francisco, 1978, 3 vols., 1539.

The conference was held in San Francisco, Nov. 26–Dec. 1, 1978, and was sponsored by the U.S. National Science Foundation, UNESCO, the American Society of Civil Engineers, the Earthquake Engineering Research Inst., the Seismological Society of America, and the Universities Council for Earthquake Engineering Research. The conference consisted of seven sessions of technical papers and a panel discussion. The panel discussion is not included in the conference proceedings. A complete author index is contained in each proceedings volume. All technical papers are abstracted or cited in this volume of the *AJEE.* The following are the paper titles and authors' names.

Volume I

State-of-the-Art Session: *Seismicity and global tectonics as a framework for microzonation,* Kisslinger, C.—*Strong-motion seismology,* Jennings, P. C. and Helmberger, D. V.—*Soil & geologic effects on site response,* Donovan, N. C.—*Soil dynamics considerations for microzonation,* Sherif, M. A. and Ishibashi, I.—*Soil-structure interaction for buildings during earthquakes,* Veletsos, A. S.—*Geologic considerations for seismic microzonation,* Cluff, L. S.—*Geophysical engineering investigative techniques for site characterization,* Murphy, V. J.—*Social aspects of earthquakes,* Hutton, J. R. and Mileti, D. S.—*Urban design and earthquakes,* Lagorio, H. J. and Botsai, E.—*Earthquake insurance and microzonation,* Steinbrugge, K. V.—*Government responsibility in microzonation,* Remmer, N. S.

Microzonation Session: Progress on Seismic Zonation in the San Francisco Bay Region: *1. Introduction and summary* (not abstracted), Brabb, E. E. and Borcherdt, R. D.—*2. Neotectonic framework of central coastal California and its implications to microzonation of the San Francisco Bay region,* Herd, D. G.—*3. Progress on ground motion predictions for the San Francisco Bay region, California,* Borcherdt, R. D., Gibbs, J. F. and Fumal, T. E.—*4. A methodology for predicting ground motion at specific sites,* Archuleta, R. J., Joyner, W. B. and Boore, D. M.—*5. Liquefaction potential map of San Fernando Valley, California,* Youd, T. L. *et al.*—*6. Preliminary assessment of seismically induced landslide susceptibility,* Keefer, D. K. *et al.*—*7. Earthquake losses to buildings in the San Francisco Bay area,* Algermissen, S. T. and Steinbrugge, K. V.—*8. Examples of seismic zonation in the San Francisco Bay region,* Kockelman, W. J. and Brabb, E. E.—*9. The use of earthquake and related information in regional planning—what we've done and where we're going,* Perkins, J. B.—*The sensitivity of seismic risk maps to the choice of earthquake parameters in the Georgia Strait region of British Columbia,* Milne, W. G. and Weichert, D. H.—*The microzonation of New York State: progress report no. 2,* Fischer, J. A. and McWhorter, J. G.—*Microzonation methods and techniques used in Peru,* Kuroiwa, J. *et al.*—*Landslides from the February 4, 1976 Guatemala earthquake: implications for seismic hazard reduction in the Guatemala City area,* Harp, E. L. *et al.*—*A risk model for seismic zonation of Taiwan,* Mau, S. T. and Kao, C. S.—*Ground motion attenuation in the Philippines,* Acharya, H. K.—*A quantitative seismotectonic study of the Iranian Plateau,* Moazami-Goudarzi, K. and Parhikhteh, H.—*The Vrancea earthquake of March 4, 1977 and the seismic*

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

microzonation of Bucharest, Mandrescu, N.—*Need for experimental evidence in development of seismic microzoning methods,* Petrovski, J.—*A new proposal of the seismic risk map based on the maximum earthquake motions, the ground characteristics and the temporal variations of the seismicity,* Hattori, S.—*Seismic microzoning map of Tokyo,* Shima, E.—*Microzoning of Osaka region,* Yoshikawa, S., Iwasaki, Y. T. and Tai, M.—*Auburn Dam—a case history of earthquake evaluation for a critical facility,* Packer, D. R. *et al.*—*Computer-simulated composite earthquake hazard model for Reno, Nevada,* Bell, E. J., Trexler, D. T. and Bell, J. W.—*Zonation for critical facilities based on two-level earthquakes,* Patwardhan, A. S., Tillson, D. D. and Nowack, R. L.—*Preliminary ground response maps for the Salt Lake City, Utah, area,* Hays, W. W. *et al.*—*Application of regionalized variables to microzonation,* Glass, C. E.—*A new microzonation technique for design purposes,* Alonso, J. L. and Urbina, L.—*The concept of residual risk in earthquake risk assessments,* Patwardhan, A. S. and Cluff, L. S.—*Land use technique for microzonation,* Murakami, S. and Midorikawa, K.—*Application of seismic risk procedures to problems in microzonation,* Anderson, J. G. and Trifunac, M. D.—*Seismotectonic microzoning for earthquake risk reduction,* Schell, B. A.—*A report on the Miyagiken-oki, Japan, earthquake of June 12, 1978,* Kobayashi, H. *et al.*

Volume II

Geology, Seismology, Geophysics and Site Effects Session: *Fallacies in current ground motion prediction,* Bolt, B. A.—*Zoning for the hazard of surface fault rupture in California,* Hart, E. W.—*High-resolution geophysical surveys, a technique for microzonation of the continental shelf,* Ploessel, M. R.—*Seismicity and seismic risk related to subduction zones,* Esteva, L. and Bazan, E.—*Seismic hazards along the Makran coast of Iran and Pakistan: the importance of regional tectonics and geologic assessment,* Page, W. D. *et al.*—*Engineering and seismological observations at dams,* Negmatullaev, S. Kh. *et al.*—*Modeling strong motions from major earthquakes,* Wiggins, R. A. *et al.*—*Prediction of strong ground motion using small earthquakes,* Wu, F. T.—*Statistical analysis of strong-motion acceleration records obtained in Japan,* Iwasaki, T. *et al.*—*Analysis of source and medium effects on strong motion observations,* Shakal, A. F. and Toksoz, M. N.—*Ground motion amplification due to canyons of arbitrary shape,* Sanchez-Sesma, F. J.—*A method for assessment of seismic design motions,* Mardiross, E.—*Preliminary evaluation of site transfer functions developed from earthquakes and nuclear explosions,* Rogers, A. M. and Hays, W. W.—*The contribution of Love waves to strong ground motions,* Kudo, K.—*The relevancy of one dimensional shear models in predicting surface acceleration,* Oweis, I. S.—*Deep shear wave velocity measurement for evaluation of 1-10 sec seismic input motions,* Goto, N., Ohta, Y. and Kagami, H.—*Peak horizontal and vertical accelerations, velocities, and displacements on deep soil sites during moderately strong earthquakes,* Sadigh, K., Power, M. S. and Youngs, R. R.—*Theory of connectivity: applications to scattering of seismic waves. I. SH wave motion,* Sabina, F. J., Herrera, I. and England, R.—*On estimation of strong earthquake motions with regard to fault rupture,* Midorikawa, S. and Kobayashi, H.

Soil Dynamics, Soil-Structure Interaction and Ground Effects Session: *Constant volume cyclic simple shear testing,* Finn, W. D. L., Vaid, Y. P. and Bhatia, S. K.—*Two-dimensional pore pressure changes in sand deposits during earthquakes,* Yoshimi, Y. and Tokimatsu, K.—*Verification of liquefaction potential by field blast tests,* Arya, A. S. *et al.*—*Use of penetration data for evaluation of liquefaction potential,* Dezfulian, H. and Prager, S. R.—*A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan,* Iwasaki, T. *et al.*—*Liquefaction susceptibility map of downtown Tokyo,* Ishihara, K. and Ogawa, K.—*Three-dimensional nonlinear analysis of soil-structure interaction in a nuclear power plant containment structure,* Isenberg, J. and Vaughan, D. K.—*Boundary methods in soil-structure interaction,* Alarcon, E. *et al.*—*Seismic shear strain induced in soil deposits,* Sugimura, Y.—*Post cyclic loading behavior of soft clays,* Singh, R. D., Gardner, W. S. and Dobry, R.—*A new approach for the analysis of liquefaction of sand in cyclic shearing,* Nemat-Nasser, S. and Shokooh, A.—*A study of shear deformation process of sandy soils by the observation of acoustic emission response,* Tanimoto, K., Nishi, M. and Noda, T.—*Geotechnical data at selected strong motion accelerograph station sites,* Grant, W. P., Arango, I. and Clayton, D. N.—*Recent earthquake resistant design methods for different types of foundations in Japan,* Shioi, Y. *et al.*—*Comparison of penetration resistance values to in situ shear wave velocities,* Marcuson, III, W. F., Ballard, Jr., R. F. and Cooper S. S.—*Site effects from Fourier transforms,* Duke, C. M. and Liang, G. C.—*Dynamic characteristics of an earth dam from two recorded earthquake motions,* Abdel-Ghaffar, A. M. and Scott, R. F.—*A preliminary report on a study of the seismic response of three sediment-filled valleys in the Garm region of the USSR,* Tucker, B. *et al.*—*Empirical synthesis of seismic velocity profiles from geotechnical data,* Campbell, K. W.—*Effect of local site conditions on spectral amplification factors,* Werner, S. D. and Ts'ao, H. S.—*Determination of site dependent spectra using non linear analysis,* Lam, I., Tsai, C.-F. and Martin, G. R.—*Effects of soil inertia forces on design of buried pipelines crossing faults,* Traubenik, M. L., Valera, J. E. and Roth, W. H.—*Analysis of ground motion spectra,* Crouse, C. B. and Turner, B. E.

Volume III

Engineering Mechanics and Structural Design Session: *Selection of buildings for strong-motion instrumentation using zonation information and decision theory,* Hart, G. C. and Rojahn, C.—*Need for a comprehensive approach* *in establishing design earthquakes,* Bertero, V. V. and Mahin, S. A.—*Velocity response spectra for sites on rock or soil,* Chandrasekaran, A. R. and Paul, D. K.—*Generation of floor response spectra directly from free-field design spectra,* Chen, P. C. and Chen, J. H.—*Design spectra for stiff structures on rock,* Hisada, T. *et al.*—*On the correlation of the components of strong ground motion,* Hadjian, A. H.—*Seismic analysis of a highway bridge utilizing strong-motion acceleration records,* Iwasaki, T. and Kawashima, K.—*Buildings on isolators for earthquake protection,* Delfosse, G. C. and Miranda, J. C.—*Traveling seismic waves and structural response,* Hall, W. J., Morgan, J. R. and Newmark, N. M.—*Effective peak acceleration,* Whitman, R. V.—*A study of earthquake response spectra for offshore platforms,* Mohraz, B. and Eskijian, M. L.—*Influence of soil-structure interaction effects on dynamic response of large panel prefabricated buildings,* Petrovski, J.

Offshore Microzonation Session: *Microzonation of offshore areas: an overview,* Idriss, I. M., Cluff, L. S. and Patwardhan, A. S.—*Factors influencing seismic exposure evaluation for offshore areas,* Patwardhan, A. S.—*Seismic exposure and reliability considerations in offshore platform design,* Bea, R. G. and Akky, M. R.—*Preliminary microzonation of the Baltimore Canyon lease area,* Fischer, J. A. and Spiker, C. T.—*Seismic risk evaluation of southern California coastal region,* Selzer, L. A., Eguchi, R. T. and Hasselman, T. K.—*The uncertainty in seismic loading and response criteria,* Benjamin, J. R., Webster, F. A. and Kircher, C.—*Inelastic seismic design considerations for offshore platforms,* Nair, D., Weidler, J. B. and Hayes, R. A.—*The influence of microzonation on the reliability-based design of offshore structures,* Kappler, H. and Schueller, G. I.—*Aseismic design considerations for concrete gravity platforms,* Watt, B. J. and Byrd R. C.—*Site effects on microzonation in offshore areas,* Moriwaki, Y. and Doyle, E. H.—*Importance of surface waves in strong ground motion in the period range of 1 to 10 seconds,* Swanger, H. J. and Boore, D. M.—*Guidelines for design of offshore structures for earthquake environment,* Kallaby, J. and Mitchell, W. W.

Urban Planning, Socio-Economics and Government Responsibility Session: *The policy and administrative implications of seismic microzonation: toward logic or confusion?,* Olson, R. A.—*Toward a measure of socio-seismicity,* Abolafia, M. and Kafka, A. L.—*An evaluation study on the distribution of property losses caused by earthquakes,* Kuribayashi, E. and Tazaki, T.—*Potential for inflated building costs after disaster,* Cochrane, H. C.—*Earthquake and insurance,* Themptander, R.—*The U.S. Geological Survey's role in geologic-related hazards warning,* Nichols, D. R. and Matthews, R. A.

● **1.2-9 HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,** Japan Society of Mechanical Engineers, Tokyo [1977], 494.

The symposium was held in Tokyo from Oct. 30 to Nov. 2, 1977. Sponsored by the Japan Society of Mechanical Engineers, the symposium consisted of two general lectures and three sessions of technical papers. The following papers are abstracted or cited in this volume of the *AJEE.*

Human behavior and psychology at the time of destructive earthquake, Omote, S.—*Harmonic vibration of some structures and natural periods,* Celebi, M., Erdik, M. and Yuzugullu, O.—*Multi-dimensional nonstationary earthquake simulation,* Hoshiya, M. *et al.*—*On decline of reliability of response analysis,* Shibata, H. *et al.*—*Uncertainty analysis of seismic response of mechanical appendage system,* Suzuki, K. and Aoki, S.—*A proposal for improvement estimating the response spectrum,* Sato, H.—*The effect of the foundation structural types on earthquake resistance of large-panel buildings (according to the materials of Kizil-Kum earthquakes 1976)* (summary only), Martemyanov, A. I.—*Vertical free vibration analysis of an elastic circular cylindrical tank with a liquid,* Kondo, H.—*On strength reserves and stability of structures against seismic actions,* Aliev, G. A., Korchynsky, I. L. and Borodin, L. A.—*Aseismic design of 500KV air circuit breaker with friction dampers,* Fujimoto, S., Shimogo, T. and Arii, M.—*Hazard free operation of hydro turbines,* Khosa, J. L.—*Crush analysis of engineering structures,* Kawai, T.—*Shakedown analysis of engineering structures by using new discrete elements,* Kawai, T. and Kondou, K.—*Propagation of waves in fluid-saturated transversely isotropic poroelastic solid,* Ohnabe, H.—*Pipe rupture by seismic vibration and static repeated bending test,* Sasaki, Y. and Yoshizawa, H.—*Seismic response control of piping supported by mechanical snubber,* Honma, T. *et al.*—*Study on aseismic strength of boiler frame structure based on the investigation of its damage by Niigata earthquake,* Kajimura, Y. and Shiraki, K.—*Constructive reliability of many-storeyed buildings with a stiff core under the seismic influence,* Marjanishvili, M. A., Chanukvadze, G. Sh. and Mikabadze, Y. G.—*Application of the method of finite crossing bands for the spatial dynamic calculation of the combined buildings,* Losaberidze, A. A. and Papuashvili, Z. V.—*Optimum design problems in reliability-based structural design,* Murotsu, Y. *et al.*—*Optimal states and mathematical models of structures determined from the seismic risk problem,* Eisenberg, Ya. M., Neiman, A. I. and Abakarov, A. D.

● **1.2-10 International Symposium on Soil-Structure Interaction,** Sarita Prakashan, Meerut, India [1977], 2 vols., 815.

The symposium was held at the Univ. of Roorkee, Roorkee, India, from Jan. 3–7, 1977. The Univ. of Roorkee and eight other organizations sponsored the symposium. Volume I of the proceedings contains most of the technical papers presented at the symposium. Volume II contains seven additional technical papers. Volume II also contains the texts of six guest lectures, general reports on each of the eight themes into which the technical papers were organized, and written discussions of the papers. Only the following papers are abstracted or cited in this volume of the *AJEE.*

Volume I: *Dynamic rock behaviour in tunnelling,* Gupta, I. C. and Prem, K. S.—*Lateral pressure due to surface load on granular backfill,* Misra, B.—*Shear wall foundation interaction,* Chandrasekaran, V. S. and Khedkar, S. P.—*A tested soil-structure model for surface structures,* Kunar, R. R., Beresford, P. J. and Cundall, P. A.—*The dynamic soil-structure interaction on bridge sites,* Moss, P. J. and Carr, A. J.—*Soil-structure interaction during blasting,* Fang, H. Y. and Koerner, R. M.—*Foundation type and seismic response of buildings,* Nandakumaran, P., Paul, D. K. and Jadia, N. N.—*Soil-structure-interaction-effects in structural response to earthquake motions,* Arya, A. S. and Kumar, K.—*Foundation-soil interaction-the state-of-confusion,* Hadjian, A. H.—*Dynamic matrices of beams on elastic foundation,* Cheng, F. Y.—*Experimental coefficients for laterally loaded piles,* Pise, P. J.—*Elastic analysis of single batter piles subjected to horizontal loads,* Prajapati, A. H. and Char, A. N. R.—*Lateral load capacity of initially bent piles,* Madhav, M. R. and Rao, K. K.—*Evaluation of dynamic soil-pile constants from in-situ tests,* Puri, V. K. *et al.*—*Response of a soil-pile system during earthquakes,* Iyengar, R. N. and Reddy, A. S.—*Piles under vertical and horizontal cyclic loads in sand,* Ranjan, G. and Tyagi, G. R. S.—*Dynamic response of wells under earthquake loading,* Arya, A. S., Puri, V. K. and Prakash, R.—*Dynamic pullout resistance of anchors in sand,* Clemence, S. P. and Veesaert, C. J.—*Effect of soil structure interaction on the behaviour of machine foundation,* Bhatia, K. G. and Sinha, K. N.—*Contact shear distribution under machine foundation,* Sankaran, K. S., Subrahmanyam, M. S. and Sastri, K. R.—*Dynamics of embedded foundations-a reappraisal,* Sankaran, K. S., Subrahmanyam, M. S. and Krishnaswamy, N. R.—*Block foundation subjected to coupled modes of vibration,* Kuppusamy, T.—*Dynamic response of reciprocating compressor blocks on bored piles,* Sinha, K. N., Bagchi, J. K. and Iyenger, M.—*Soil-foundation interaction under sinusoidal and impact type dynamic loads,* Wedpathak, A. V., Pandit, V. K. and Guha, S. K.—*Dynamic interaction of a dam reservoir foundation system,* Finn, W. D. L. and Varoglu, E.—*Finite element analysis of some soil-structure interaction problems,* Desai, C. S. and Patil, U. K.—*Interaction problems of well foundation and piers,* Fukuoka, M.

Volume II: *Analysis of single and group piles,* Agarawala, S. K. *et al.*

● **1.2-11 Earthquake engineering and soil dynamics,** Proceedings of the ASCE Geotechnical Engineering Div. Specialty Conference, American Society of Civil Engineers, New York, 1978, 3 vols., 1599.

The conference was held June 19-21, 1978, in Pasadena, California. Sponsors included the ASCE Geotechnical Engineering Div. and eight other organizations. The proceedings consists of three volumes. Volumes I and II contain technical papers presented at the conference. Volume I also contains state-of-the-art reports on the stress-strain behavior of soils and dynamic soil property measurement; these reports are not abstracted in this volume of the *AJEE.* Volume III includes state-of-the-art reports on earthquake ground motion characteristics and soil dynamics analysis and a synopsis of the summary session. The volume also covers specialty sessions on the following topics: nuclear power plants, buildings, lifeline earthquake engineering, the engineering of fixed offshore platforms to resist earthquakes, slopes and embankments, problems in selecting design earthquakes, modeling, lateral pressures, risk and probability, and design for fault displacement. The state-of-the-art reports and specialty sessions are not abstracted in the Abstract Journal. Volumes II and III contain a subject index for all three volumes and Volume III contains an author index for all three volumes.

The following technical papers from Volumes I and II are abstracted or cited in this volume of the *AJEE.*

Volume I: *Estimating in situ shear moduli at competent sites,* Anderson, D. G., Espana, C. and McLamore, V. R.—*In-situ and laboratory shear velocity and modulus,* Arango, I., Moriwaki, Y. and Brown, F.—*A directional structure index related to sand liquefaction,* Arulanandan, K. and Kutter, B.—*Design earthquake motions based on geologic evidence,* Bell, J. M. and Hoffman, R. A.—*Measuring dynamic in situ geotechnical properties,* Bratton, J. L. and Higgins, C. J.—*Influence of faulting on earthquake attenuation,* Bureau, G. J.—*Dynamic properties of lime and LFA treated soils,* Chae, Y. S. and Chiang, J. C.—*Seismic design of retaining walls and cellular cofferdams,* Chakrabarti, S. *et al.*—*Saturation effects on the cyclic strength of sands,* Chaney, R. C.—*Prediction of free-field earthquake ground motions,* Crouse, C. B.—*Soil-structure interaction for footing foundations,* Dawson, A. W.—*Dynamic modulus and damping relationships for sands,* Edil, T. B. and Luh, G.-F.—*Critical state model for cyclic load pore pressure,* Egan, J. A. and Sangrey, D. A.—*Compliance function of footing in two-layer medium,* Ettouney, M. M. and Kar, A. K.—*Response spectra for soft soil sites,* Faccioli, E.—*Cyclic pore pressures under anisotropic conditions,* Finn, W. D. L. *et al.*—*Comparison of dynamic analyses for saturated sands,* Finn, W. D. L., Martin, G. R. and Lee, M. K. W.—*Ground motion induced interface pressures,* Higgins, C. J.—*A small explosive simulation of earthquake-like ground motions,* Higgins, C. J., Simmons, K. B. and Pickett, S. F.—*Magnitude-dependent near source-ground motion spectra,* Johnson, J. A. and Traubenik, M. L.—*Simplified seismic analysis for tailings dams,* Klohn, E. J. *et al.*—*Constitutive equation for cyclic behavior of cohesive soils,* Krizek, R. J., Ansal, A. M. and Bazant, Z. P.

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

Volume II: *Analysis of Chabot Dam during the 1906 earthquake,* Makdisi, F. I., Seed, H. B. and Idriss, I. M.—*Effect of load form and sample reconstitution on test results,* Marcuson, III, W. F. *et al.*—*Simulation of lateral pile behavior under earthquake motion,* Matlock, H., Foo, S. H. C. and Bryant, L. M.—*Dynamic properties of hard glacial till,* Murphy, D. J. *et al.*—*Aseismic design of offshore platforms,* Nair, V. V. D.—*Liquefaction potential at an ocean outfall in Puerto Rico,* Nataraja, M. S., Wong, I. H. and Toto, J. V.—*Stiffness and damping of piles in layered media,* Novak, M. and Aboul-Ella, F.—*Earthquake response of buried pipeline,* O'Rourke, M. and Wang, L. R. L.—*Post-cyclic strength of marine limestone soils,* Prager, S. R. and Lee, K. L.—*Mathematical modeling of cyclic soil behavior,* Prevost, J. H. and Hughes, T. J. R.—*Post-earthquake stability analysis of earth dams,* Ramanujam, N., Holish, L. L. and Chen, W. W. H.—*The dynamic response of anisotropic clay,* Saada, A. S., Bianchini, G. F. and Shook, L. P.—*Drainage effects on seismic stability of rockfill dams,* Sadigh, K., Idriss, I. M. and Youngs, R. R.—*Cyclic shear strength of variably cemented sands,* Salomone, L. A., Singh, H. and Fischer, J. A.—*Cyclic loading of sands, silts and clays,* Sangrey, D. A. *et al.*—*Dynamic response of a sand under random loadings,* Shen, C. K. *et al.*—*Analysis of cyclic simple shear test data,* Shen, C. K., Herrmann, L. R. and Sadigh, K.—*Stochastic seismic stability prediction of earth dams,* Singh, M. P. and Khatua, T. P.—*Dynamic response of block foundations,* Srinivasulu, P. *et al.*—*Vibration studies on jolter foundations,* Srinivasulu, P. *et al.*—*Variables affecting in situ seismic measurements,* Stokoe, II, K. H. and Hoar, R. J.—*Dynamic response of San Francisco Bay mud,* Stokoe, II, K. H. and Lodde, P. F.—*Damping in saturated soil,* Stoll, R. D.—*Cyclic triaxial and SPT for predicting liquefaction,* Townsend, F. C., Marcuson, III, W. F. and Mulilis, J. P.—*Simplified determination of dynamic stresses in earth dams,* Vrymoed, J. L. and Calzascia, E. R.—*Seismic velocities of San Francisco Bayshore sediments,* Wilson, R. C., Warrick, R. E. and Bennett, M. J.—*Impedance function of a group of vertical piles,* Wolf, J. P. and von Arx, G. A.—*Compaction and cyclic shear strength of granular backfill,* Wong, I. H., Abdelhamid, M. S. and Fischer, J. A.—*Shear devices for determining dynamic soil properties,* Wright, D. K., Gilbert, P. A. and Saada, A. S.—*Shallow slides due to 1971 San Fernando earthquake,* Yen, B. C. and Trotter, J. R.—*Finite element analysis of stress propagation in a clay,* Yong, R. N. and Lee, H.-P.—*San Fernando faulting damage and its effect on land use,* Youd, T. L., Yerkes, R. F. and Clark, M. M.

● **1.2-12** Noland, J. L. and Amrhein, J. E., eds., **North American Masonry Conference Proceedings,** Univ. of Colorado, Boulder, Aug. 1978, 1300.

The conference, held Aug. 14-16, 1978, at the Univ. of Colorado, Boulder, was sponsored by the Masonry Society. The proceedings includes technical papers and an author index. Thirty-six papers pertinent to earthquake engineering are abstracted or cited in this volume of the *AJEE.* The paper titles and authors' names follow.

Behavior of concrete masonry under biaxial stresses, Hegemier, G. A., Nunn, R. O. and Arya, S. K.—*Grout-block bond strength in concrete masonry,* Nunn, R. O., Miller, M. E. and Hegemier, G. A.—*On the behavior of joints in concrete masonry,* Hegemier, G. A. *et al.*—*Current masonry research at the British Ceramic Research Association,* West, H. W. H.—*Behavior of concrete masonry structures and joint details using small scale direct models,* Harris, H. G. and Becica, I. J.—*The parameters influencing shear strength between clay masonry units and mortar,* Nuss, L. K., Noland, J. L. and Chinn, J.—*The interaction of masonry wall panels and a steel frame,* Colville, J. and Ramseur, R.—*The effect of joint reinforcement on vertical load carrying capacity of hollow concrete block masonry,* Hatzinikolas, M., Longworth, J. and Warwaruk, J.—*The influence of flaws, compaction, and admixture on the strength and elastic moduli of concrete masonry,* Miller, M. E., Hegemier, G. A. and Nunn, R. O.—*Prism tests for the compressive strength of concrete masonry,* Hegemier, G. A. *et al.*—*On nonlinear response predictions of concrete masonry assemblies,* Arya, S. K. and Hegemier, G. A.—*A design guide for reinforced and prestressed brickwork,* Haseltine, B. A.—*Masonry in building codes,* Dickey, W. L.—*A structural engineer's rationalization of the masonry building code,* Pyle, D. T. and Weber, D. C.—*The Center for Educational Development - a medium scale seismic upgrading,* Davis, H. A.—*Low cost facility for testing the ultimate earthquake resistance of masonry structures,* Keightley, W. O.—*An investigation of the dynamic response of the Park Lane Towers to earthquake loadings,* Medearis, K.—*Seismic research on multistory masonry buildings, University of California, Berkeley, 1972 to 1977,* Mayes, R. L. *et al.*—*An experimental investigation on the seismic behavior of single-story masonry houses,* Gulkan, P. *et al.*—*Stability under seismic loading of buildings with fully cracked wall-floor joints,* Nachbar, W. and Furgerson, R.—*High rise building vibration properties: an unexpected behavior mechanism,* Oppenheim, I. J.—*Interaction between unreinforced masonry structures and their roof diaphragms during earthquakes,* Adham, S. A. and Ewing, R. D.—*How the high lift grouting system was developed,* Person, O. F.—*The use of concrete unit masonry in nuclear power plants,* Grant, J. M. and Wu, A. Y.—*Surface bonding cement: a new technology for masonry,* Klausmeier, R. D.—*An application of thin wall masonry,* Pyle, D. T.—*Case study - computerized design for load bearing masonry,* Vannoy, D., Harvey, H. E. and Colville, J.—*Automated design of multistory masonry shear wall structures,* Hill, Jr., L. A. and Chasey, Jr., R. H.—*Some fundamental factors in the structural design of masonry buildings,* Hendry, A. W.—*An automated desk method for analyzing load bearing masonry structures,* Van Pelt, J. M.—*Rational analysis of masonry structures,* Colville, J. and Vannoy, D.—*The benefits of high-strength*

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masonry, Froerer, D. D.—*Basic principles of structural mechanics of tall masonry buildings*, Mikluchin, P. T.—*Progressive collapse of masonry structures*, Amrhein, J. E.—*Modern loadbearing masonry construction in the western United States*, Mock, J. R.—*A nonferrous reinforced concrete masonry structure*, Flandro, A. W.

● **1.2-13 Offshore Technology Conference—1978, Proceedings of Tenth Annual,** Offshore Technology Conference, Dallas, Texas, 1978, 4 vols., 2682.

The conference was held in Houston, May 8-10, 1978. It was sponsored by eleven international engineering and scientific societies. In addition to the four proceedings volumes, a separate index includes an alphabetic 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, authors' names, and paper numbers (in parentheses) follow.

Volume I: *Reliability analysis format for offshore structures* (OTC 3046), Moses, F.—*Nonlinear design of offshore structures under extreme loading conditions* (OTC 3047), Kamil, H.—*Earthquake excitation of submerged tanks and caissons: a correlation study for physical and analytic models* (OTC 3110), Byrd, R. C. and Nilrat, F.—*Seismic risk analysis with combined random and nonrandom earthquake occurrence* (OTC 3111), Arnold, P.—*Application of effective stress methods for offshore seismic design in cohesionless seafloor soils* (OTC 3112), Finn, W. D. L., Martin, G. R. and Lee, M. K. W.—*Seismic risk for offshore structures* (OTC 3113), Wiggins, R. A., Sweet, J. and Frazier, G. A.

Volume II: *Earthquake survivability of concrete platforms* (OTC 3159), Watt, B. J. *et al.*—*The effect of liquid storage tanks on the dynamic response of offshore platforms* (OTC 3162), Vandiver, J. K. and Mitome, S.

Volume III: *The Texas ocean-bottom seismograph* (OTC 3223), Latham, G. *et al.*—*Experimental study on the liquefaction of sandy seabed under offshore oil storage tanks* (OTC 3258), Kobayashi, H. and Nagatsuka, M.—*Behavior of seafloor soils subjected to cyclic loading* (OTC 3260), Herrmann, H. G. and Houston, W. N.

Volume IV: *Pile response to dynamic lateral loading* (OTC 3309), Hwong, S. T., Ghazzaly, O. I. and O'Neill, M. W.—*Example of soil-pile coupling under seismic loading* (OTC 3310), Matlock, H., Foo, S. H. C. and Cheang, L. C. C.—*Quantitative study of slope instability in the Gulf of Alaska* (OTC 3314), Hampton, M. A. *et al.*

● **1.2-14 Stress and strain measurements related to earthquake prediction,** Proceedings of Conference VII, National Earthquake Hazards Reduction Program, *Open-File Report 79-370*, Office of Earthquake Studies, U.S. Geological Survey, Menlo Park, California, 1978, 651.

The seventh conference in the continuing series under the Earthquake Hazards Reduction Program was held in Carmel, California, on Sept. 7-9, 1978. Fifteen papers relevant to earthquake engineering are abstracted or cited in this volume of the *AJEE*. The paper titles and authors' names follow.

Some remarks on the base length of tilt and strain measurements, Berger, J. and Wyatt, F.—*Tilt measurements on a small tropical island*, Bilham, R. and Beavan, J.—*Progress in monitoring stress changes near active faults in southern California*, Clark, B. R.—*Total field measurements on the San Andreas fault near Gorman, California*, Searls, C. A. *et al.*—*Periodic high precision gravity observations in southern California*, Fett, J. D.—*Tiltmeter results from Adak*, Harrison, J. C., DeMay, J. M. and Meertens, C.—*Measurements of tilt in the New Hebrides island arc*, Isacks, B. L. *et al.*—*Measurements of local magnetic field, observations of fault creep, and local earthquakes on the San Andreas fault, California*, Johnston, M. J. S., Smith, B. E. and Mueller, R. M.—*Electrical measurements as stress-strain monitors*, Madden, T. R.—*Tiltmeter research at New Madrid and at Adak: the stability and reliability of shallow bore-hole tiltmeters*, Morrissey, S.-T. and Stauder, W.—*The analysis of tiltmeter data*, Mortensen, C. E.—*The Terra Tek stress monitoring system: theory, calibration and data from the Palmdale area, California and Salt Lake City, Utah*, Pratt, H. R. and Hardin, E. H.—*Crustal deformation and aseismic fault slip near Hollister, California*, Slater, L. E.—*Tilt elbows before earthquakes*, Stuart, W. D. and Herriot, J. W.—*Reports on observations of crustal stress and crustal deformation, and their anomalous changes related to earthquakes in China*, Tanaka, Y.

● **1.2-15 Sixth European Conference on Earthquake Engineering,** Yugoslav Assn. for Earthquake Engineering, Ljubljana, 1978, 6 vols., 1490.

The conference was held in Dubrovnik, Yugoslavia, from Sept. 18-22, 1978. Sponsors included the Yugoslav Assn. for Earthquake Engineering and six other organizations. All papers are abstracted or cited in this volume of the *AJEE*. The paper titles and authors' names follow.

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and Zelensky, G. A.—*Design principles of the gravity seismic isolated structures for civil housing,* Katen-Yartsev, A. S. *et al.*—*Comparative seismic risk analysis of different buildings in the same site,* Petrini, V.—*Relative influence of selected structural parameters on the inelastic seismic response of isolated structural walls,* Derecho, A. T. *et al.*—*Parametric investigation of non-linear shear wall structures,* Pekau, O. A. and Gocevski, V.—*Moment-axial force interaction in coupled shear walls,* Gocevski, V. and Pekau, O. A.—*Modeling of shear wall structures for seismic analysis,* Lee, J. P. and Chokshi, N. 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F.—*A mathematical model for the seismic behavior of reinforced concrete critical regions as influenced by moment and shear,* Atalay, M. B.—*Computer-aided seismic resistant design of R/C multistory frames,* Bertero, V. V. and Zagajeski, S. W.—*Repair of bond in R/C structures by epoxy injection,* Cowell, A. D., Popov, E. P. and Bertero, V. V.—*The influence of non-elastic properties of the reinforced concrete on the performance of the frame constructions under seismic loads,* Orudgev, F. M. *et al.*—*Plastic deformations requested to R/C structures during strong earthquakes. Influence of the mechanical decay by taking into account the P-Δ effect,* Braga, F. and Parducci, A.—*Response of partially prestressed members to repeated overloads,* Babu, K. G.—*Methodology for strengthen existing structures built without the required earthquake resistance,* Oliveira, C. 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V.—*Seismic analysis of gravity dams taking into consideration the deformation of foundation rock,* Ungureanu, N.—*Stochastic investigation of gravity dams subjected to earthquake loading,* Kisliakov, S.—*Nonlinear seismic response of concrete gravity dams,* Bicanic, N. *et al.*—*Earthquake resistance of a gravity dam-reservoir-foundation system,* Wieland, M.—*Soil-dam-fluid interaction,* Bickovski, V.—*Improved finite element analysis for computing the seismic response of dam-reservoir systems,* Breaban, V. and Barbat, H.—*Complete earthquake analysis of the dam-foundation ground system,* Negoita, A. and Breaban, V.—*General system concept of interaction problem in seismic analysis for reservoir system-flat upstream dam,* Vulpe, A., Poterasu, V. 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The symposium, held in Tokyo during Nov. 1978, was sponsored by the Architectural Inst. of Japan, the Japan Society of Civil Engineers, the Japan Society of Mechanical Engineers, the Japanese Society of Soil Mechanics and Foundation Engineering, and the Seismological Society of Japan. At the back of the proceedings volume, the contents are listed in English. Those papers abstracted or cited in this volume of the *AJEE* follow.

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● 1.2-17 Iwan, W. D., ed., **Strong-motion earthquake instrument arrays,** Proceedings of the International Workshop on Strong-Motion Earthquake Instrument Arrays, California Inst. of Technology, Pasadena, 1978, 103.

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

The workshop, held May 2-5, 1978, in Honolulu, was convened by the International Assn. for Earthquake Engineering. The National Science Foundation and the United Nations Educational, Scientific and Cultural Organization were the sponsors. The goal was to develop a workable plan for the possible future deployment of dense strong-motion earthquake instrument arrays with primary emphasis on ground motion studies. Three potential areas of array application—source mechanism studies, wave propagation studies, and studies of local effects—were considered. To achieve its stated goal, the workshop was organized into five working subgroups. The areas covered by the subgroups were favorable array locations, array design for source mechanism and wave propagation studies, array design for local effects studies, array construction and operation, and implementation. The reports of the subgroups are incorporated as chapters in the publication.

● **1.2-18** Prange, B., Gudehus, G. and Borm, G. W., eds., **Dynamical methods in soil and rock mechanics,** A. A. Balkema, Rotterdam, 1978, 3 vols., 1074.

This three volume publication represents the proceedings of an international symposium and a NATO advanced study institute organized by the Inst. of Soil and Rock Mechanics of the Univ. of Karlsruhe. The symposium was held in Karlsruhe on Sept. 5-16, 1977. The proceedings will be of interest to researchers and to practicing engineers dealing with dynamically and cyclically loaded structures and environmental vibration problems. Volume 1 covers dynamic response and wave propagation in soils; Volume 2, plastic and long-term effects in soils; and Volume 3, rock dynamics and geophysical aspects. Each volume separately lists its contributors. Because of scheduling constraints, none of the papers are abstracted in the Abstract Journal.

● **1.2-19** **Proceedings of the Japan-U.S. Seminar on HTGR Safety Technology, Seismic Research, Volume 1,** held at Brookhaven National Lab., Upton, New York, Sept. 15-16, 1977, *BNL-NUREG-50689-Vol. 1,* Brookhaven National Lab., Upton, New York, 1977, 349.

● **1.2-20** Holand, I. *et al.,* **Safety of structures under dynamic loading,** Tapir Publishers, Trondheim, Norway, 1978, 2 vols., 882.

This international research seminar was held June 23–July 1, 1977, at the Norwegian Inst. of Technology in Trondheim. It was sponsored by this institute and 11 other institutions. The seminar dealt with the modern probability-based theories of structural reliability and stochastic dynamics, with special emphasis on applications to wind and ocean engineering. Thirteen internationally recognized experts gave unified presentations of the selected topics. These lectures form a coherent exposition at an advanced level, and are arranged in the four main chapters which form the first volume of this publication. The second volume comprises the contributions of participants who presented papers on their own research and engineering activities. The following papers pertain to the field of earthquake engineering. Because of scheduling constraints, none of these papers are abstracted in this volume of the *AJEE.*

Volume 1: *Introduction to random processes,* Crandall, S. H.—*Response of linear time-invariant dynamic systems,* Crandall, S. H.—*Stochastic response of multimodal systems,* Crandall, S. H.—*Failure under random vibration,* Crandall, S. H.—*Wide-band random vibration of structures,* Crandall, S. H.—*Random vibration of non-linear systems,* Broch, J. T.—*Interpretation and simulation of earthquake ground motions as nonstationary stochastic processes,* Solnes, J.—*Reliability-based structural codes optimization theory,* Lind, N. C.—*Reliability-based structural codes practical calibration,* Lind, N. C.—*Safety level decisions and socio-economic optimization,* Lind, N. C.—*On the second moment structural reliability theory,* Ditlevsen, O.

Volume 2: *Response of nonlinear oscillators subjected to random excitation,* Smith, E.—*Manifestation of vibration damage in a structure,* Skjei, R. E.—*Seismic behavior of flexible cylindrical tanks,* Clough, D. P.—*Synopsis of some recent research on reliability formats,* Veneziano, D.—*On the reliability of a one-degree-system loaded by a rotating unbalance,* Grundmann, H.

● **1.2-21** Ward, P. L., ed., **Proceedings of Conference IV—The Use of Volunteers in the Earthquake Hazards Reduction Program,** convened under auspices of National Earthquake Hazards Reduction Program, Feb. 2-3, 1978, *Open-File Report 78-336,* U.S. Geological Survey, Menlo Park, California, 1978, 273.

● **1.2-22** **N.S.F. seminar-workshop-strong ground motion** [California Inst. of Technology, Pasadena], 1978, 102.

The seminar, which was partly sponsored by the geophysical and earthquake engineering research programs within the National Science Foundation, was held at Rancho Santa Fe, California, on Feb. 12-15, 1978. The publication contains a list of participants, the program schedule, a statement on proposed directions of future research, and the 22 papers presented at the seminar. The paper titles and authors are listed below; because of scheduling constraints, none are individually abstracted in this volume of the *AJEE.*

Quantitative prediction of strong motion for a potential earthquake fault, Aki, K. *et al.*—*Recent developments and applications of deterministic earthquake models: prediction of near- and far-field ground motion,* Archambeau, C. B.—*Application of system identification techniques for local site characterization,* Beck, J. L.—*Radiated seismic energy*

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

and the implications of energy flux measurements for strong motion seismology, Boatwright, J.—*Intensity and regression,* Bolt, B. A.—*Modeling of near-fault motions,* Boore, D. M.—*A dynamic source model for the San Fernando earthquake,* Bouchon, M.—*Alternative ground motion intensity measures,* Cornell, C. A.—*Let's be mean,* Donovan, N. C.—*Measures of high-frequency strong ground motion,* Hanks, T. C.—*Synthesis of San Fernando strong-motion records,* Heaton, T. H. and Helmberger, D. V.—*SH propagation in a layered half-space,* Herrmann, R. B.—*Statistics of pulses on strong motion accelerograms,* Housner, G. W.—*An introduction to strong-motion instruments and data,* Jennings, P. C.—*The application of synthetic seismograms to the study of strong ground motion,* Johnson, L. R. and Helmberger, D. V.—*Semi-empirical approach to prediction of ground motions produced by large earthquakes,* Kanamori, H.—*Deterministic modeling of source mechanisms utilizing near- and far-field seismic data: the 1971 San Fernando earthquake,* Langston, C. A.—*Occurrence of strong ground motions,* Matthiesen, R. B.—*The needs of the Nuclear Regulatory Commission in the field of strong motion seismology,* Reiter, L.—*Some thoughts on the definition of the input earthquake for the seismic analysis of structures,* Roesset, J. M.—*Simulations of earthquake ground motions,* Wiggins, R. A. *et al.*

● **1.2-23** Bathe, K. J., ed., **Applications using ADINA,** Proceedings of a conference held Aug. 1977, *Report 82448-6,* Acoustics and Vibration Lab., Massachusetts Inst. of Technology, Cambridge, 1977, 424.

● **1.2-24** **Proceedings of the Ninth International Conference on Soil Mechanics and Foundation Engineering,** Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, 1978, 3 vols., 2036.

The conference was held in Tokyo in 1977. The proceedings are in three volumes. Each volume includes an author index. Volumes 2 and 3 have papers and reports relevant to earthquake engineering. Volume 2 contains technical papers of interest and a state-of-the-art report on soil dynamics and its application to foundation engineering; Volume 3 contains a special lecture on the geotechnical aspects of construction of the Shinkansen train system in Japan and organizers' reports on Specialty Session No. 9, "Constitutive Equations of Soils," and Specialty Session No. 10, "The Effects of Horizontal Loads on Piles, due to Surcharge or Seismic Effects." For information concerning session No. 9, see Abstract No. 1.2-25. Only those technical papers from Volume 2 listed below are abstracted or cited in this volume of the *AJEE.*

Input seismic motion for the use in soil dynamics, Asada, A. (4/1)—*Seismic effects of the soils of Peru,* Carrillo-Gil, A. (4/5)—*Siting structures in seismic liquefaction areas,* Ferritto, J. M. and Forrest, J. B. (4/9)—*Dynamic effective stress analysis of sands,* Finn, W. D. L., Lee, K. W. and Martin, G. R. (4/10)—*A liquefaction case history, Chiapas, Mexico,* Flores-Berrones, R. J. and Dawson, A. W. (4/11)—*Dynamic shear tests of soils for seismic analyses,* Hara, A. and Kiyota, Y. (4/13)—*Isolation of vibrations by concrete core walls,* Haupt, W. A. (4/14)—*P- and S-wave velocities of the ground in Japan,* Imai, T. (4/15)—*Liquefaction of anisotropically consolidated sand,* Ishihara, K. *et al.* (4/16)—*Soil liquefaction and stability of foundation,* Ivanov, P. L. and Sinitsyn, A. P. (4/17)—*Earthquake analysis of Fort Peck Dam, Montana,* Marcuson, III, W. F., Krinitzsky, E. L. and Kovanic, E. R. (4/21)—*Geotechnical model for seismic microzonation,* Martinez, A. and Romani, F. (4/22)—*Dynamic behaviour of soil supported foundations,* Mirza, W. H. (4/23)—*Practical method of predicting sand liquefaction,* Nishiyama, H. *et al.* (4/24)—*Soil-pile-foundation interaction,* Novak, M. (4/25)—*Dynamic strength of saturated cohesive soil,* Ogawa, S., Shibayama, T. and Yamaguchi, H. (4/26)—*Modelling soil behaviour under cyclic loading,* Pender, M. J. (4/28)—*Free vibration characteristics of piles,* Prakash, S. and Chandrasekaran, V. (4/29)—*Dynamical behaviour of piles in nonlinear stratified soil,* Rodriguez Ortiz, J. M. and Castanedo, J. (4/33)—*Horizontal vibrations-new lumped parameter model,* Sankaran, K. S., Subrahmanyam, M. S. and Sastri, K. R. (4/35)—*Dynamic interaction of rigid foundations,* Savidis, S. A. and Richter, T. (4/36)—*The effect of fines on liquefaction of sands,* Shen, C. K., Vrymoed, J. L. and Uyeno, C. K. (4/38)—*Dynamic properties of a marine sediment,* Sherif, M. A., Ishibashi, I. and Ling, S. C. (4/39)—*Dynamic behaviour of soils and sub-surface ground,* Shibata, T., Sato, T. and Soelarno, D. S. (4/40)—*On the problem of the dynamic stability of soils,* Sperling, G. and Hausner, H. (4/43)—*Pore pressure parameters and sand liquefaction,* Tinoco, F. H. (4/44).

● **1.2-25** **Constitutive equations of soils,** Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, 1978, 310.

This publication contains the proceedings of Specialty Session 9 held on July 13, 1977, during the Ninth International Conference on Soil Mechanics and Foundation Engineering in Tokyo. Those papers pertinent to earthquake engineering are listed below; none of these papers are abstracted or cited in this volume of the *AJEE.* Abstract No. 1.2-24 contains a list of some of the papers presented at the conference.

Constitutive equations for sand in simple shear, Finn, W. D. L., Lee, K. W. and Martin, G. R.—*Effects of deviatoric stress history on the constitutive equations of particulate material,* Murayama, S.—*Elastic moduli of undrained clayey soils based on clay-water-electrolyte system,* Nakagawa, K. *et al.*—*Deformations of dry sand under cyclic loadings,* Tokue, T.

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

● **1.2-26** **Proceedings of the International Symposium on Computer Aided Seismic Analysis and Discrimination,** held June 9-10, 1977, in Falmouth, Massachusetts, Inst. of Electrical and Electronics Engineers, Long Beach, California, 1977, 122.

● **1.2-27** **Summer Seismic Institute for Architectural Faculty,** AIA Research Corp., Washington, D.C. [1977], 321.

This institute was held at Stanford Univ. from August 7-12, 1977. The National Science Foundation (RANN) sponsored the institute. The purpose of the meeting was to bring the seismic hazard to the attention of the architectural community. The institute participants were faculty members from schools of architecture from throughout the U.S. This publication includes papers based on the lectures given at the institute; a section describing the strategies developed at the institute for incorporating seismic design into schools of architecture; and a final section that lists available resources, such as books, movies and slides, abstract and information services, periodicals, and a list of participants.

The following papers were presented at the institute; because of scheduling constraints, none of the papers have been abstracted individually in this volume of the *AJEE*. *The architect's role in seismic design,* Botsai, E. E.—*Geologic concepts of earthquakes,* Cluff, L. S.—*Land use planning for seismic safety,* Mader, G. G.—*Soils and earthquakes,* Donovan, N. C.—*Seismic design: structural concepts,* Degenkolb, H. J.—*Seismic design: architectural systems and components,* Fisher, J. L.—*Seismic design: building nonstructural systems,* Merz, K. L.—*Seismic building code development,* Zacher, E. G.—*Seismic registration for architects,* Crawley, S.—*Existing buildings and seismic safety,* Bresler, B.—*Architectural restoration for seismic safety,* Worsley, J. C.—*Planning and design of strong-motion instrument networks,* Matthiesen, R. B.—*Seismic public policy and the design professional,* Steinbrugge, K. V.—*The John A. Blume Earthquake Engineering Center,* Gere, J. M.—*National Science Foundation Earthquake Engineering Program,* Scalzi, J. B.

● **1.2-28** Zienkiewicz, O. C. *et al.*, eds., **Numerical methods in offshore engineering,** Proceedings of Symposium held at Swansea, Jan. 1977, John Wiley & Sons, Chichester, England, 1978, 581.

● **1.2-29** **Instrumentation for ground vibration and earthquakes,** Institution of Civil Engineers, London, 1978, 172.

This publication covers the proceedings of the conference of the Society for Earthquake and Civil Engineering Dynamics held in Keele, England, on July 4-5, 1977. Two review papers, one on recording earthquakes and the other on ground vibration instrumentation, introduce 14 papers on various specific topics. Discussion on the papers is included in the publication. The following papers are abstracted in this volume of the *AJEE*. Paper numbers appear in parentheses.

Recording earthquakes, Willmore, P. L. (1)—*Assessment of seismic hazard in the UK,* Burton, P. W. (3)—*Detection and location of earthquakes and unplanned explosions,* Browitt, C. W. A. (6)—*Specification of instrumentation for estimating and monitoring ground motion from earthquakes,* Long, R. E. (8)—*Analysis and correction of ground and structure motion recordings,* Medearis, K. G. and Wilson, J. (11)—*Contributions of early instrumental seismic recordings to engineering analysis,* Papastamatiou, D. (12).

● **1.2-30** Aki, K. and Duda, S. J., eds., **Quantification of earthquakes,** *Tectonophysics,* 49, *3/4,* Sept. 1, 1978, 159.

Reported in this issue of *Tectonophysics* are the results of the Workshop on the Quantification of Earthquakes held in Aug. 1977 as part of the Durham Assembly of the International Assn. of Seismology and Physics of the Earth Interior. This issue includes 22 papers and a summary of the workshop. Six of these papers pertinent to earthquake engineering are listed below; none are abstracted individually in this volume of the *AJEE*. *Earthquake source and propagation parameters in New Zealand,* Adams, R. D.—*Observed and probable intensity zoning of Iran,* Mohajer-Ashjai, A. and Nowroozi, A. A.—*Statistical test theory in the analysis of macroseismic questionnaires,* Ringdal, F. *et al.*—*Magnitudes of larger earthquakes not included in the Gutenberg-Richter's magnitude catalogue,* Miyamura, S.—*A new magnitude-frequency relation,* Lomnitz-Adler, J. and Lomnitz, C.—*Characterization of high-frequency strong ground motion* (abstract only), Hanks, T. C.

● **1.2-31** Bergan, P. G. *et al.*, eds., **Finite elements in nonlinear mechanics,** Proceedings of International Conference on Finite Elements in Nonlinear Solid and Structural Mechanics, held at Geilo, Norway, Aug. 1977, Tapir, Trondheim, Norway, 1978, 2 vols., 906.

● **1.2-32** Sundararajan, C., ed., **Dynamic analysis of pressure vessel and piping components,** *PVP-PB-022,* American Society of Mechanical Engineers, New York, 1977, 107.

This volume contains six papers presented at two sessions on "Computer Methods for the Dynamic Analysis of Pressure Vessel and Piping Components" during the ASME Energy Technology Conference held in Houston, Texas, on Sept. 18-23, 1977. Two of the papers, listed below, are pertinent to the field of earthquake engineering. Neither is abstracted individually in this volume of the *AJEE* because of scheduling constraints. *The influence of boundary conditions upon the axisymmetric vibration of a*

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

shallow spherical shell, Brown, S. J. and Wu, J. N. C.—*Improving approximations in soil-structure dynamic interaction analysis,* Hsu, M. B. and Melosh, R. J.

● 1.2-33 Evernden, J. F., ed., **Proceedings of Conference II—Experimental Studies of Rock Friction with Application to Earthquake Prediction,** convened under auspices of National Earthquake Hazards Reduction Program, Apr. 28–30, 1977, U.S. Geological Survey, Menlo Park, California, 1977, 701.

● 1.2-34 Bertero, V. V., organizer, **Proceedings of a Workshop on Earthquake-Resistant Reinforced Concrete Building Construction,** Univ. Extension, Univ. of California, Berkeley, June 1978, 3 vols., 1941.

The workshop was held July 11–15, 1977, at the Univ. of California, Berkeley. It was sponsored by the National Science Foundation. The main purposes of the meeting were to provide a means for the exchange of information related to the state-of-the-art and state-of-the-practice in the design and construction of seismic-resistant reinforced concrete buildings, to evaluate current progress, and to establish research needs and priorities for the future. The specific objectives and organization of the workshop are summarized in the introduction to the first volume. The final recommendations of the workshop form the main body of that volume. Four appendixes follow, containing the program, the list of participants, the list of working groups, and a research directory.

The second and third volumes comprise the technical reports and papers that were presented at the workshop. These furnished the background material for the discussions which ultimately resulted in recommendations. Following is a list of these papers; because of scheduling constraints, none are individually abstracted in this volume of the *AJEE.*

Volume II

An Overview of the State-of-the-Art in Earthquake Resistant Reinforced Concrete Building Construction: *An overview of the state-of-the-art in earthquake resistant reinforced concrete building construction in the United States of America,* Blume, J. A.—*An overview of the state-of-the-art in earthquake resistant concrete building construction in Canada,* Uzumeri, S. M., Otani, S. and Collins, M. P.—*A European view on earthquake-resistant reinforced concrete building construction,* Borges, J. F.—*A review of recent research in Japan as related to the earthquake resistant design of reinforced concrete building structures,* Aoyama, H.—*Seismic design requirements on a Mexican 1976 code,* Rosenblueth, E.—*Earthquake resistant reinforced concrete buildings in Mexico: research needs and practical problems,* Esteva, L.—*Accomplishments and research and development needs in New Zealand,* Park, R.—*Design earthquakes–uncertainties in ground motion input and their effects on building construction,* Donovan, N. C.—*State-of-the-art in establishing design earthquakes,* Bertero, V. V.—*Uncertainties in seismic input and response parameters–development of stable design parameters,* Shah, H. C. and Mortgat, C. P.

An Overview of the State-of-the-Practice in Earthquake-Resistant Reinforced Concrete Building Construction: *Evolution of codes and standards for earthquake-resistant reinforced concrete building construction (ERCBC),* Sharpe, R. L.—*Summary of present codes and standards in the world,* Watabe, M.—*Seismic code based on semi-probabilistic approach,* Benjamin, J. R.—*The purpose and effects of earthquake codes: a case study of semiprobabilistic approach,* Shah, H. C. and Zsutty, T. C.—*An overview of user needs for improving earthquake-resistant reinforced concrete building construction,* Olsen, B. C.—*An overview of the state-of-the-practice and of user needs for improving ERCBC. (emphasis on California),* Teal, E. J.—*An overview of the state-of-the-practice and of user needs for improving ERCBC–Canadian aspects,* Knoll, F.—*User needs for improving earthquake-resistant reinforced concrete building construction,* Zacher, E. G.

User Needs: *Earthquake research and user needs,* Bresler, B.—*Applicability of earthquake research from the user's viewpoint,* Wyllie, Jr., L. A.

Keynote Address: *Social and economic effects of earthquake prediction,* Turner, R. H.

Mechanical Characteristics and Performance of Reinforced and Prestressed Concrete Materials Under Seismic Conditions: *Mechanical properties of concrete,* Preece, F. R.—*Constitutive relations for concretes under seismic conditions,* Taylor, M. A.—*Confined concrete: research and development needs,* Bertero, V. V. and Vallenas, J.—*Strength and ductility of reinforced concrete columns with rectangular ties,* Uzumeri, S. M. and Sheikh, S. A.—*A note on the failure criterion for diagonally cracked concrete,* Collins, M. P.—*Mechanical characteristics and performance of reinforcing steel under seismic conditions,* McDermott, J. F.—*Mechanical characteristics and bond of reinforcing steel under seismic conditions,* Popov, E. P.—*Constitutive relations of steel: effects on hysteretic behaviour of structural concrete members and on strength considerations in seismic design,* Park, R.—*Development length requirements for reinforcing bars under seismic conditions,* Hawkins, N. M.

Reinforced and Prestressed Concrete Structural Systems, Including Types of Foundations: Importance of Conceptual Design: *Structural systems for earthquake resistant concrete buildings,* Fintel, M. and Ghosh, S. K.—*Soft story concept applied at St. Joseph Health Care Center,*

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

Popoff, Jr., A.—*The 18-storied Shiinamachi Building,* Ohmori, N.—*State of the art of precast concrete technique in Japan,* Ikeda, A. *et al.*—*Methods for repairing and retrofitting (strengthening) existing buildings,* Warner, J.—*Methods and costs of reinforcing Veterans Administration existing buildings,* Leftner, J.—*Repair and strengthening of reinforced concrete members and buildings,* Hanson, R. D.

Methods of Structural Analysis: *The art of modeling buildings for dynamic seismic analysis,* Gates, W. E.—*Modeling of reinforced concrete buildings,* Selna, L. G.—*Problems in the practical application of computer analysis to reinforced concrete building design,* Poland, C. D.—*Effects of two dimensional earthquake motion on response of R/C columns,* Pecknold, D. A. and Suharwardy, M. I. H.—*An overview of the state-of-the-practice of the usage of computer programs,* Brandow, G.—*Computer programs for analysis of seismic response of reinforced concrete buildings,* Powell, G. H.—*Elastic analysis of walls with openings,* Popov, E. P.—*Computer aided design of earthquake resistant reinforced concrete buildings,* Greve, N. R.—*On the use of computers in the seismic-resistant design of reinforced concrete buildings,* Mahin, S. A.

Volume III

Design Methods and Experimental and Analytical Investigations Related to the Earthquake-Resistant Reinforced Concrete Building Construction of Moment-Resisting Frames; Correlation with Field Observations of Earthquake Damage: *Design of reinforced concrete moment-resisting frames,* Strand, D. R.—*Capacity design of reinforced concrete ductile frames,* Paulay, T.—*Reinforced concrete ductile frames–the use of diagonal reinforcing to solve the joint problem,* Poole, R. A.—*The problem of damage to nonstructural components and equipment,* Merz, K. L.—*Problem of damage to non-structural components and equipment: walls and stairs,* McKenzie, G. H.—*Computer-aided optimum design of ductile R/C moment-resisting frames,* Zagajeski, S. W. and Bertero, V. V.—*Experimental and analytical investigations of reinforced concrete frames subjected to earthquake loading,* Gergely, P.—*Behavior of elements and subassemblages–R.C. frames,* Jirsa, J. O.—*A method for delaying shear strength decay of RC beams,* Scribner, C. F. and Wight, J. K.—*Reinforcing bars in earthquake-resistant reinforced concrete building construction,* Black, W. C.—*Seismic response constraints for slab systems,* Hawkins, N. M.

Design Methods and Experimental and Analytical Investigations Related to the Earthquake-Resistant Reinforced Concrete Building Construction of Frame-Wall Structures; Correlation with Field Observations of Earthquake Damage: *Design of frame-wall structures,* Derecho, A. T.—*Design of reinforced concrete frame-wall structures: criteria and practical considerations,* Elsesser, E.—*Earthquake resistant structural walls,* Paulay, T.—*Design of R/C frame-wall structures,* Takeda, T.—*A practical method to evaluate seismic capacity of existing medium- and low-rise R/C buildings with emphasis on the seismic capacity of frame-wall buildings,* Umemura, H. and Okada, T.—*Shear wall researchable items,* Meehan, J. F.—*Laboratory tests of earthquake-resistant structural wall systems and elements,* Fiorato, A. E. and Corley, W. G.—*Importance of reinforcement details in earthquake-resistant structural walls,* Fiorato, A. E., Oesterle, R. G. and Corley, W. G.—*Coupling beams of reinforced concrete shear walls,* Paulay, T.

Foundations and Retaining Structures: *Seismic rocking problem of rigid compensated foundations,* Zeevaert, L.—*Comments on structure-soil interactions during earthquakes,* Wyllie, L. A.—*Comments on structure-soil interactions during earthquakes,* Holmes, W. T.—*Cast-in-field reinforced concrete systems for new buildings–design of foundations,* Teixeira, S. E.

Experimental Investigations of Real Buildings, Models of Complete Buildings, and Large Subassemblages of Buildings; Correlation with Analytical Investigations and with Data from Field Observations of Earthquake Damage: *Dynamic response investigations of real buildings,* Freeman, S. A., Honda, K. K. and Blume, J. A.—*Experimental investigations–correlation with analysis,* Shepherd, R. and Jennings, P. C.—*Large-scale dynamic shaking of 11-story reinforced concrete building,* Mayes, R. L. and Galambos, T. V.—*Dynamic behavior of an eleven-story masonry building,* Stephen, R. M. and Bouwkamp, J. G.—*Strong-motion instrumentation of reinforced concrete buildings,* Rojahn, C.—*Earthquake simulation in the laboratory,* Sozen, M. A.—*The experimental investigation on ERCBC with emphasis on the use of earthquake response simulators in Japan,* Okada, T.—*Use of earthquake simulators and large-scale loading facilities in ERCBC,* Bertero, V. V., Clough, R. W. and Oliva, M.—*Experimental research needs for earthquake-resistant reinforced concrete building construction,* Krawinkler, H.

Design Methods and Experimental and Analytical Investigations Related to the Earthquake-Resistant Reinforced Concrete Building Construction of Prestressed and Prefabricated Structures; Correlation with Field Observations of Earthquake Damage: *Design of earthquake-resistant, prestressed concrete structures,* Lin, T. Y., Kulka, F. and Tai, J.—*Design of prestressed concrete structures,* Park, R.—*Seismic design of precast concrete panel buildings,* Becker, J. M. and Llorente, C.—*An evaluation of the state of the art in the design and construction of prefabricated buildings in seismically active areas of the United States,* Englekirk, R. E.—*Some aspects of application and behaviour of large panel systems in seismic regions of Europe,* Velkov, M. and Jurukovski, D.—*Earthquake resistant design of precast concrete bearing wall type structures–a designer's dilemma,* Mujumdar, V. S.—*Seismic resistance vs. progressive collapse of precast concrete panel buildings,*

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

Fuller, G. R.—*Production and repair aspects of industrialized buildings for ERCBC,* Hester, W. T.—*Analytical and experimental studies of prestressed and precast concrete elements,* Hawkins, N. M.—*Experimental investigations of subassemblages of partially prestressed and prestressed concrete framed structures,* Park, R. and Thompson, K. J.

● 1.2-35 **Advisory Meeting on Earthquake Engineering and Landslides,** Proceedings of Meeting held Aug. 29–Sept. 2, 1977, in Taipei [n.p.], 1977, 353.

1.2-36 **Contribution of geophysical methods to seismic zoning,** *Bollettino di Geofisica,* XX, *78,* June 1978, 95–219.

This special issue contains the Proceedings of the 2nd Course of the International School of Applied Geophysics, held at the East Majorana Centre for Scientific Culture, Erice, Univ. of Milano, Italy, from April 13-23, 1977. The papers listed below are pertinent to earthquake engineering. Only those papers with asterisks after the titles are abstracted or cited in this volume of the *AJEE.* The remainder of the papers are short contributions or summaries.

*The new elements on the map of seismic zoning,** Bune, V. I.—*Attenuation of intensities with distance for shallow earthquakes in the area of Greece,** Drakopoulos, J. C.—*On some problem of engineering seismology,** Kobayashi, H.—*A method for seismic microzoning maps on the basis of subsoil conditions,** Kobayashi, H.—*Status and prospects for national seismic hazard and zoning maps in the United States,** Perkins, D. M.—*Prospects for the use of geologic data in United States hazard maps,** Perkins, D. M.—*Acceleration hazard map sensitivity to input seismic parameters,** Perkins, D. M.—*Frequency-magnitude statistical parameters with reference to some zoning problems* (short contribution), Cosentino, P.—*Seismic risk map for southern Italy: preliminary results* (short contribution), Panza, G. F. and Calcagnile, G.—*General principles of seismic zoning,* Beloussov, V. V.—*Geological and geophysical data used for delineation of zones with different M_{MAX} on the Caucasus,* Bune, V. I.—*Seismic investigations in the Vachsh area of Tazhikskaja SSR relating to Nurek Dam,* Bune, V. I.—*A mechanical model for the statistic of earthquakes magnitude moment and fault distribution,* Caputo, M.—*The importance of a complete microzonation procedure and reliability of the existing methods,* Drakopoulos, J.—*The national network of seismographs and strong motion accelerographs in Greece,* Drakopoulos, J.—*Seismic risk and zonation procedure in Greece,* Drakopoulos, J.—*Microzonation in the seismic area of Korinth-Luotraki,* Drakopoulos, J., Leventakis, G. and Roussopoulos, A.—*Ground characteristics and seismic bedrock motions,* Kobayashi, H.—*Global tectonics and seismic zoning,* Lomnitz, C.—*Seismic data processing for seismotectonic investigations,* Lomnitz, C.—*Earthquake origin zones as a basis for seismic zoning maps,* Shebalin, N. V.—*Preparation of initial macroseismic and instrumental data for purposes of seismic zoning,* Shebalin, N. V.—*Seismotectonics and seismic regional zoning in peninsular Italy,* Shenkareva, G. A.

● 1.2-37 Sundararajan, C., ed., **Probabilistic analysis and design of nuclear power plant structures,** *PVP-PB-030,* American Society of Mechanical Engineers, New York, 1978, 117.

During the Winter Annual Meeting of the American Society of Mechanical Engineers, held Dec. 10–15, 1978, in San Francisco, the ASME Design and Analysis Committee of the Pressure Vessels and Piping Division held the symposium represented in this publication. Three of the symposium's seven papers pertain to the field of earthquake engineering and are abstracted in this volume of the *AJEE: Stochastic seismic response analysis of hysteretic multi-degree-of-freedom structures,* Wen, Y.-K.—*Liquefaction and probability,* Chou, I.-H. and Fischer, J. A.—*Combination of dynamic loads,* Gupta, A. K.

● 1.2-38 **Abstracts of Papers, 73rd Annual Meeting Seismological Society of America, April 6-8, 1978, Sparks, Nevada,** *Earthquake Notes,* 49, *1,* Jan.–Mar. 1978, 102.

● 1.2-39 **50th Annual Meeting, Eastern Section of the Seismological Society of America, Weston Observatory, Boston College, Weston, Massachusetts, Oct. 16-18, 1978, Program and Abstracts,** *Earthquake Notes,* 49, *3,* July–Sept. 1978, 3–31.

● 1.2-40 **The Seismological Society of America, 1979 Annual Meeting, May 21-23, Green Center, Colorado School of Mines, Golden, Colorado, Program and Abstracts,** *Earthquake Notes,* 49, *4,* Oct.–Dec. 1978, 5–112.

This issue contains the program, abstracts, and an author index for the 1979 Annual Meeting of the Seismological Society of America. Those abstracts relevant to earthquake engineering are included in the following sessions: strong motion, seismicity, premonitory phenomena, Oaxaca - 29 November 1978, site amplification and hazard, Oaxaca and other recent events, influence of the near surface, synthetics and discrimination, recent sources and San Andreas, digital seismology, San Andreas plate margin, and epicenter location and attenuation.

● 1.2-41 **American Geophysical Union, 1978 Spring Meeting, Program and Abstracts,** *EOS, Transactions of the American Geophysical Union,* 59, *4,* Apr. 1978, 251–418.

The 1978 Spring Meeting of the American Geophysical Union was held in Miami Beach, Florida, from Apr. 17–21. This issue of *EOS* contains the preliminary program, abstracts of papers presented at the meeting, and an author index. Those abstracts relevant to earthquake engineering are contained in the following sessions. Page numbers appear in parentheses.

Seismology: Computer Applications in Seismology/ Seismicity Studies (316); Instrumentation/Upper Mantle (318); Sources, Mechanisms, and Magnitude Determinations (326); Earthquake Prediction, 1 (327); Earthquake Prediction, 2 (329).

Tectonophysics: Seismicity, Seismic Structure, Transforms, and Geometry of Ridges (369); Rock Deformation, 2: Miscellaneous (375); Rock Fracture (378); Faults, Ophiolites, and Structural Modeling (385).

● 1.2-42 **American Geophysical Union, 1978 Fall Annual Meeting, Program and Abstracts,** EOS, *Transactions of the American Geophysical Union,* 59, *12,* Dec. 1978, 1042–1234.

The 1978 Fall Meeting of the American Geophysical Union was held in San Francisco, Dec. 4–8. This issue of *EOS* contains the preliminary program, abstracts of papers presented at the meeting, and an author index. Those abstracts relevant to earthquake engineering are contained in the following sessions. Page numbers appear in parentheses.

Geodesy: Geodetic and Geophysical Crustal Anomalies in Southern California (1051).

Seismology: Seismic Gaps and Recurrence Intervals (1124); Premonitory Seismicity and Earthquake Mechanisms (1126); Synthetic Accelerograms and Ray Tracing (1128); Santa Barbara Earthquake and the Stephen's Pass Earthquake Swarm (1130); Instrumentation and Automation (1131); Plate-Mantle Structure and Seismicity (1134); Source Studies, Normal Modes, and Attenuation (1139).

Tectonophysics: Attenuation of Elastic Waves in Rocks (1182); Fracture and the Physics of Cracks in Rocks (1191); Geochemical Measurements Pertinent to Earthquake Prediction (1195); Mechanics of Earthquake Instabilities and Precursors (1204); Rock Friction and the Properties of Fault Zone Materials (1207); Large-Scale Faulting and Earthquakes: Geologic, Geodetic, and Stress Measurements (1209).

● 1.2-43 Ang, A. H.-S., **Report of the US-Southeast Asia Symposium on Engineering for Natural Hazards Protection,** *UILU-ENG-78-2002, Structural Research Series No. 445,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, Jan. 1978, 43.

Symposium delegates from the U.S. and the Southeast Asian countries reviewed the current states of technologies for the design of facilities and structures to resist the extreme forces of natural hazards, with specific reference to earthquakes and strong wind. Current research and development efforts in the U.S. and Southeast Asia were reviewed, and the problems which are unique to each region in the protection against natural hazards were discussed. Abstract No. 1.2-3 contains a list of papers presented at the symposium.

● 1.2-44 **Living with the seismic code,** Structural Engineers Assn. of Southern California, Los Angeles, 1978, 245.

The symposium was held Mar. 7 and Mar. 14, 1978, in Los Angeles, California. The sponsor was the Structural Engineers Assn. of Southern California. Papers presented at the symposium are related to the following four topics: (1) characteristic site period; (2) building response; (3) code forces and irregular buildings; and (4) dynamic analysis and response spectrum. None of the papers are abstracted or cited in this volume of the *AJEE.*

● 1.2-45 **Universities Council for Earthquake Engineering Research, Proceedings of Fifth National Meeting,** *Report UCEER-5,* Universities Council for Earthquake Engineering Research, California Inst. of Technology, Pasadena, 1978, 285.

The meeting was held at the Massachusetts Inst. of Technology, June 23–24, 1978. The purposes were to provide a vehicle for the exchange of information related to current and projected university research in earthquake engineering, to evaluate progress in specific areas of research, and to establish goals and priorities for future work. One hundred fifty individuals, representing 67 universities, governmental agencies, and industries, attended the meeting. Ninety-five brief research reports were presented in six sessions: Session 1—Ground motion; Session 2—Soils & soil structure interaction; Session 3—Structural elements; Session 4—Structural response, experimental; Session 5—Structural response, analytical; Session 6—Seismic risk, seismic design & codes. This publication contains summaries of the presented reports and some summaries that were not presented orally. In addition to the research presentations, there was a special session on "Recent Developments in Federal Support for Earthquake Engineering Research." This session was conducted by personnel from the National Science Foundation, Div. of Problem-Focused Research Applications.

● 1.2-46 **New perspectives on the safety of dams,** Proceedings of a Seminar and Workshop, Stanford Univ. and Massachusetts Inst. of Technology, Stanford, California, 1978, var. pp.

A five-day seminar and workshop was held from Aug. 28 to Sept. 1, 1978, at Stanford Univ. The seminar was cosponsored by Stanford Univ. and the Massachusetts Inst. of Technology. A partial list of the contents includes: Report

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of the Federal Coordinating Council for Science, Engineering and Technology, Ad Hoc Interagency Committee on Dam Safety Program; *Effective state dam safety supervision,* Dukleth, G. W.—*California's dam safety program,* Doody, J. J.—*Dam safety and judgement under uncertainty,* Slovic, P.—*Building in the age of uncertainty: an engineer's obligation regarding natural hazards: impact of continuity of engineering on construction schedule,* D'Appolonia, E.—*Statistical decision theory applied to dams,* Benjamin, J. R.—*Embankment dams - UC - June 75 cavitation in conduits and spillways,* Cooke, J. B.—*Spillway dams with aeration of the flow over spillways* (reprint), Semenkov, V. M.—*Geologic perspectives on earthquake hazards and dam safety,* Cluff, L. S.—*Dam safety: seismic hazard assessment,* Cornell, C. A.—*The performance of earth dams during earthquakes,* Seed, H. B. *et al.*—*Selected list of references on identification of hazards associated in landsliding in reservoirs,* Schuster, R. L.—*Decision analysis in dam safety monitoring,* Vanmarcke, E. H.—"New perspectives on the safety of dams, parts 1-2," reprinted from *International Water Power & Dam Construction,* **30,** *10 & 11,* 1978. The papers are not abstracted in this volume of the *AJEE.*

● 1.2-47 **Conference on Structural Analysis, Design & Construction in Nuclear Power Plants** (in English, in Portuguese, or in Spanish with English summaries), Proceedings of conference held in Porto Alegre, Brazil, April 18-20, 1978, Pos-Graduacao em Engenharia Civil, Univ. Federal do Rio Grande do Sul, Porto Alegre, Brazil, 1978, 3 vols.

● 1.2-48 **Current state of knowledge of lifeline earthquake engineering,** Proceedings of ASCE Technical Council on Lifeline Earthquake Engineering Specialty Conference, American Society of Civil Engineers, New York, 1977, 478.

The conference was held at the Univ. of California, Los Angeles, Aug. 30-31, 1977. In addition to the main sponsor, the ASCE Technical Council on Lifeline Earthquake Engineering, there were nine cosponsors. The publication contains technical papers, state-of-the-art papers, and subject and author indexes. The paper titles and authors' names follow. Because of scheduling constraints, none of these papers are abstracted in this volume of the *AJEE.*

Gas and Liquid Fuel Lifelines: *General considerations for seismic design of oil pipeline systems,* Kennedy, R. P., Darrow, A. C. and Short, S. A.—*Seismic design criteria for pipelines and facilities,* Hall, W. J. and Newmark, N. M.—*Lifeline earthquake engineering for trans Alaska pipeline system,* Anderson, T. L. and Nyman, D. J.—*Seismic response analysis procedure for the trans Alaska pipeline,* Powell, G. H. and Mondkar, D. P.

Transportation Lifelines: *State-of-the-art review: earthquake-resistant design of transportation lifelines,* Bertken, T. G.—*Measurement of earthquake performance of transportation systems,* Britz, K. I., Edelstein, P. H. and Oppenheim, I. J.—*Bridge retrofitting selection of critical bridges in a road network,* Longinow, A., Bergmann, E. and Cooper, J. D.—*Retrofitting highway structures to increase seismic resistance,* Degenkolb, O. H.—*Maintaining transportation lifelines,* Kozak, J. J.

Special Session: *Present state of lifeline earthquake engineering in Japan,* Kubo, K., Katayama, T. and Ohashi, A.

Water and Sewage Lifelines: *Earthquake protection of water and sewage lifelines,* Jansen, R. B.—*The Metropolitan Water District's earthquake program,* Smith, Jr., D. J.—*Impact of earthquakes on service connections and water meters,* Lund, L. V.—*Practical design of earthquake resistant steel reservoirs,* Miles, R. W.—*Measuring the earthquake performance of urban water systems,* Erel, B. *et al.*

Electrical Power and Communication Lifelines: *Communications lifelines in earthquakes,* Foss, J. W.—*Protecting a power lifeline against earthquakes,* Steinhardt, O. W.—*Advances in mitigating seismic effects on power systems,* Schiff, A. J.—*Aseismic design of 500KV air circuit breaker with friction dampers,* Shimogo, T. and Fujimoto, S.

Underground Pipes: *State of the art of buried lifeline earthquake engineering,* Wang, L. R. L. and O'Rourke, M. J.—*Underground pipelines in a seismic environment,* Isenberg, J. *et al.*—*A review of the earthquake response and aseismic design of underground piping systems,* Ariman, T.—*Underground pipe damages and ground characteristics,* Shinozuka, M. and Kawakami, H.—*Behavior of underground box conduit in the San Fernando earthquake,* Hradilek, P. J.—*Lifeline viability of rock tunnels: empirical correlations and future research needs,* Dowding, C. H.

Seismic Criteria: *Fault displacement and ground deformation associated with surface faulting,* Taylor, C. L. and Cluff, L. S.—*Fundamental concept of aseismic design of earthquake resistant lifeline systems and industrial facilities,* Shibata, H. and Tsuchiya, M.—*Seismic design and qualification procedures for equipment components of lifeline systems,* Merz, K. L.—*State of California Strong Motion Instrumentation Program,* Wootton, T. M.

Seismic Risk: *Lifeline seismic criteria and risk: a state of the art report,* Shah, H. C. and Benjamin, J. R.—*Vulnerability of transportation and water systems to seismic hazard methodology for hazard cost evaluation,* Oppenheim, I. J.—*Damage probability for a water distribution system,* Whitman, R. V. and Hein, K. H.—*Seismic risk analysis of the State Water Project,* Eskel, A. E.—*Practical reliability*

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assessment of a linear lifeline, Benjamin, J. R. and Webster, F. A.

Investigation and Research: *Research needs in lifeline earthquake engineering,* Parmelee, R. A.—*California water and power earthquake engineering forum,* Lund, L. V.—*Learning from the earthquake behavior of lifelines,* Moran, D. F. and Duke, C. M.

● 1.2-49 Kupfer, H., Shinozuka, M. and Schueller, G. I., eds., **2nd International Conference on Structural Safety and Reliability, Proceedings,** Werner-Verlag, Dusseldorf, West Germany, 1977, 724.

The conference was held at the Technische Univ. Munchen in Munich from Sept. 19-21, 1977. In addition to technical papers and short contributions, the proceedings contain an author index. The following papers are pertinent to earthquake engineering. Because of scheduling constraints, none of these papers are abstracted in this volume of the *AJEE*.

Session I—Analytical Methods in Structural Safety and Reliability: *Time and space domain analysis in the structural reliability assessment,* Shinozuka, M.—*Reliability analysis of continuous structures,* Benjamin, J. R. and Reed, J. W.—*On the reliability of statically indeterminate structures with particular reference to load combinations,* Schwarz, R. F.—*On the reliability of structures under periodic loading,* Grundmann, H.

Session II—Codified Design: *Implementation of probabilistic safety concepts in international codes,* Borges, J. F.—*Representation of loads for code purposes,* Cornell, C. A. and Larrabee, R. D.—*Policies for selection of target safety levels,* Sexsmith, R. G. and Lind, N. C.

Session III—Shore- and Offshore Structures; Large Dams: *Reliability assessment of offshore platforms in seismic regions,* Yang, J. N. and Freudenthal, A. M.—*Lessons from experience and research on the safety of dams,* Serafim, J. L.

Session IV—Nuclear Structures: *External hazards in reliability and risk assessment of nuclear power plants,* Stevenson, J. D.—*Reliability-based design of the containment of a PWR,* Schueller, G. I. and Bauer, J.

Session V—Earthquake- and Wind-Exposed Structures: *Safety and reliability analysis of long span suspension bridges subjected to earthquake and wind forces,* Konishi, I. and Takaoka, N.—*Optimum regionalization,* Rosenblueth, E.—*Seismic risk analysis: a look at the state of the art,* Shah, H. C. and Mortgat, C. P.—*Seismic zoning as a problem of optimization,* Grandori, G.

Session VI—Application in Planning, Construction and Management: *Structural optimization and risk control,* Kupfer, H. and Freudenthal, A. M.—*Catastrophe potential: simulation and control,* Berz, G. A.—*Analysis and acceptance of risks from an underwriter's point of view,* Kohler, W.

● 1.2-50 **Douglas McHenry International Symposium on Concrete and Concrete Structures,** *SP-55,* American Concrete Inst., Detroit, 1978, 661.

The symposium was held Oct. 29, 1976, in conjunction with the ACI-IMCYC Fall Convention in Mexico City. The publication includes 10 papers dealing with plain concrete, 14 papers dealing with concrete structures, closing remarks, and a combined author-subject index. The papers listed below are pertinent to earthquake engineering. Paper numbers are in parentheses. Because of scheduling constraints, none of these papers are abstracted in this volume of the *AJEE*.

The nature of mass concrete in dams (SP-55-6), Raphael, J. M.—*Prediction of response of concrete buildings to severe earthquake motion* (SP-55-23), Freeman, S. A.—*Destructive vibration test of a 4-story concrete structure* (SP-55-24), Chen, C. K., Czarnecki, R. M. and Scholl, R. E.

● 1.2-51 **Seminar on Constructions in Seismic Zones, Bergamo, Italy, 10th - 13th May, 1978, Preprints,** International Assn. for Bridge and Structural Engineering and Ist. Sperimentale Modelli e Strutture, n. p., 1978, 159.

The following papers were presented at the seminar. Paper numbers appear in parentheses. None of these papers are abstracted in this volume of the *AJEE* because of scheduling constraints.

Design Criteria for Structures in Seismic Zones: *Some fundamental aspects of earthquake engineering* (1/1), Ifrim, M.—*Column uplift during seismic response of buildings* (1/2), Clough, R. W. and Huckelbridge, A. A.—*Effect of construction joints on vibrations of structures* (1/3), Celebi, M., Erdik, M. and Yuzugullu, O.—*Seismic resistance of reinforced concrete high rise buildings structural elements* (1/4), Anicic, D.—*Low cost seismic design and construction* (1/5), Tarpy, Jr., T. S., McCreless, C. S. and Hauenstein, S. F.—*Engineering decisions and seismic risk prevention* (1/6), Grandori, E., Grandori, G. and Petrini, V.—*The GAPEC system: a new aseismic building method founded on old principles* (1/7), Delfosse, G. C.—*Recent New Zealand developments on bridge seismic design* (1/8), Blakeley, R. W. G. and Chapman, H. E.—*Aseismic design of multi-story space frames* (1/9), Raghavan, T. M. S. and Nigam, N. C.

Repairs and Reconstruction of the Structures: *Post earthquake construction of Gediz* (2/1), Gurpinar, A.—*Structural repair of monumental masonry buildings* (2/2),

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Albanesi, S. *et al.*—*Strengthening of masonry buildings* (2/3), Benedetti, D. and Vitiello, E.—*A way to increase the resistance of supporting structures that are already built against seismic forces* (2/4), Marinakis, K.

Effects of Recent Earthquakes in Italy and Other Countries: *Friuli earthquakes 1976. Strong motion accelerograph records* (3/1), Mihailov, V.—*Structural behaviour of the damaged building during the Friuli earthquakes between May 6 and September 15, 1976* (3/2), Heimgartner, E.—*Behaviour of large panel building during the Romania earthquake of March 4, 1977* (3/3), Velkov, M.—*Nonlinear seismic behaviour of Magurele building - Bucharest, during the earthquake of March 4, 1977* (3/4), Simeonov, B.—*Effects of Vrancea earthquake of 4 March 1977 on the territory of Bulgaria* (3/5), Sachanski, S.—*Behaviour of brick masonry buildings during earthquakes* (3/6), Bayulke, N.—*Considerations concerning earthquake response analysis of rockfill dams* (3/7), Priscu, R., Stematiu, D. and Ilie, L.—*Surface effects on seismic waves at mountain sites* (3/8), Castellani, A., Riccioni, R. and Robutti, G.—*Quantitative appraisal of destructive earthquakes* (3/9), Papastamatiou, D.

Seismic Efficiency of Large Structures (Recommendations, Checking and Surveillance): *Problems in assessing the effects of earthquake on dams,* Lane, R. G. T.—*The consequences of partially grouted joints upon the arch dam seismic behaviour* (4/1), Priscu, R., Popovici, A. and Stere, C.—*Ductility of reinforced concrete columns* (4/2), Bo, G. M. and Capurro, M.—*Seismic design and verification of seismic efficiency of a highrise reinforced concrete building* (4/3), Muto, K. and Sugano, T.—*Problems found during the seismic design of structures and equipments of a nuclear power plant* (4/4), Lazzeri, L., Bozzo, F. and Filippi, G.—*Seismic behaviour of guyed masts* (4/5), Fischer, O.—*Earthquake-resistant design of submerged tunnels* (4/6), Okamoto, S. and Tamura, C.—*On the modelling of sea-bed resistance for seismic response analysis of offshore pipelines in contact with the sea-bed* (4/7), Nath, B. and Soh, C. H.—*Contribution of the surveillance to the evaluation of the seismic efficiency of dams. Example of the Ambiesta Dam* (4/8), Castoldi, A.

Supplementary Papers: *The earthquake of 23 November, 1977 in Caucete, San Juan, Argentina,* Carmona, J. S.—*A systematic analysis for the structures of a building to be restored,* Guerra, G.—*Some aspects of the methodology of restoration and renewal of buildings damaged in the 1976 Friuli earthquakes,* Conti, M. and Fantoni, L.—*Behaviour of an aseismic structure during Caucete earthquake of November 23, 1977,* Bruschi, S.—*Damage to bridges during the north Caucasus earthquakes,* Shestoperov, G. S.—*Dynamic response of building with isolation on rubber cushions,* Petrovski, J., Jurukovski, D. and Simovski, V.—*Seismic design for central nuclear en embalse - Cordoba,* Bruschi, S.

● **1.2-52** **The assessment and mitigation of earthquake risk,** *Natural Hazards, 1,* United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris, 1978, 341.

The Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk was held in Paris at UNESCO headquarters in Feb. 1976. This publication contains revised and expanded versions of the papers presented at the conference. The papers are organized into three subject areas: assessment of earthquake risk, engineering measures for loss reduction, implications of earthquake risk. None of the papers are abstracted in this volume of the *AJEE.*

● **1.2-53** Dubey, R. N. and Lind, N. C., eds., **Mechanics in engineering,** *SM Study 11,* Solid Mechanics Div., Univ. of Waterloo, Waterloo, Canada, 1977, 403.

The First ASCE-EMD (American Society of Civil Engineers-Engineering Mechanics Div.) Specialty Conference on Mechanics in Engineering was held at the Univ. of Waterloo, May 26-28, 1976. The two papers listed below are applicable to earthquake engineering. Because of scheduling constraints, neither of these papers is abstracted in this volume of the *AJEE.*

Finite element modelling of inelastic behaviour, Argyris, J. H. and Willam, K. J.—*Concrete structural response due to surface blast,* Wu, S. T.

● **1.2-54** Silver, M. L. and Tiedemann, D., co-chmn., **Dynamic geotechnical testing,** *ASTM Special Technical Publication 654,* American Society for Testing and Materials, Philadelphia, 1978, 398.

This publication contains nineteen papers presented at a symposium held in Denver, Colorado, June 28, 1977. The symposium was sponsored by the American Society for Testing and Materials' Committee D-18 on Soil and Rock for Engineering Purposes. All papers are applicable to earthquake engineering. Because of scheduling constraints, none of the papers are abstracted in this volume of the *AJEE.*

● **1.2-55** Noor, A. K. and McComb, Jr., H. G., **Trends in computerized structural analysis and synthesis,** Pergamon Press, New York, 1978, 430.

This publication contains 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 symposium was sponsored by the George Washington Univ. and the Langley Research Center of the U.S. National Aeronautics and Space Admin., in cooperation with the National Science Foundation and the

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American Society of Civil Engineers. The papers are organized into the following sections: (1) future directions of structural applications and potential of new computing systems; (2) advances and trends in data management and engineering software development; (3) advances in applied mathematics and symbolic computing; (4) computer-aided instruction and interactive computer graphics; (5) nonlinear analysis; (6) dynamic analysis and transient response; (7) structural synthesis; (8) structural analysis and design systems; (9) advanced structural applications; (10) supercomputers, numerical analysis and trends in software systems. The papers included in the first nine sections also appear in *Computers & Structures*, **10**, *1/2*, Apr. 1979. None of the papers are abstracted in this volume of the *AJEE*.

● **1.2-56 Earthquake hazards and local government liability,** Assn. of Bay Area Governments, Berkeley, California, 1978, 35.

The conference was held on Dec. 8, 1978, in San Francisco. This report contains outlines of the panel presentations on the following topics: (1) Can local governments be held liable for injuries and damage caused by their failure to reduce known or suspected earthquake hazards?; (2) How does potential liability affect local government decisions about earthquake hazards?; (3) How can local government best cope with its potential liability related to earthquake hazard reduction?; and (4) Recommended changes in state policies. Also included is a summary of important court decisions related to government liability.

● **1.2-57 Sixth Symposium on Earthquake Engineering, Vol. 1,** Sarita Prakashan, Meerut, India, 1978, 583.

The symposium was held Oct. 5-7, 1978, at the Univ. of Roorkee, Roorkee, India. It is planned that two proceedings volumes will be published; Volume 2 has not yet been published. The papers in Volume 1 are organized into the following sessions: seismology and tectonics; soil dynamics and foundation behaviour; dynamic properties and structural response analysis; and earthquake resistant analysis and design of buildings. None of these papers are abstracted or cited in this volume of the *AJEE* because of scheduling constraints.

● **1.2-58 International Congress on Earthquake Protection of Constructions in Seismic Areas (1978: Bucharest)** (in English, Romanian, or French), Romania, Central Inst. for Research, Design and Guidance in Civil Engineering, Bucharest, 1978, 2 vols. and 45 pp. monograph.

The congress, held Nov. 22-24, 1978, in Bucharest, was organized under the auspices of the Conference Permanente des Ingenieurs du Sud-Est de l'Europe. The papers are organized into the following sessions: Vol. 1—Seismic risk assessment; Behaviour of structures during recent strong earthquake motions; Vol. 2—Design codes and criteria for structures in seismic zones; and aseismic protection and related problems. Because of scheduling constraints, none of the papers are abstracted in this volume of the *AJEE*.

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2. Selected Topics in Seismology

2.1 Seismic Geology

2.1-1 Armbruster, J., Seeber, L. and Jacob, K. H., **The northwestern termination of the Himalayan mountain front: active tectonics from microearthquakes,** *Journal of Geophysical Research,* 83, *B1,* Paper 7B0415, Jan. 10, 1978, 269-282.

The seismicity of the northwestern Himalayan syntaxial bend and the geologically complex area to the west, between the Hazara thrust system (HTS) and the higher mountains of Indus-Kohistan, is examined in a wider tectonic context by using data from approximately 1800 microearthquakes. The microearthquake data were obtained from a telemetered seismic network in northern Pakistan centered at Tarbela Dam on the Indus River and were collected during an 11-month period prior to impounding of the Tarbela reservoir. The observed seismicity indicates that a branch of the main boundary thrust (MBT) traverses the region as a straight northwesterly extension of the Murree thrust, the mapped section of the MBT southeast of the syntaxial bend along the Kashmir Himalayas. Seismic release on this extension of the MBT, here named the Indus-Kohistan seismic zone (IKSZ), is highest in the upper 25 km of the crust and correlates with a pronounced topographic step. Deeper activity on the IKSZ extends to a depth of 70 km. Seismicity in the lower crust defines a second lineation 100 km southwest of the IKSZ and parallel to it.

The syntaxial bend and the eastern HTS, virtually inactive microseismically at present but associated with recent and historical microseismicity, overprint the two northwesterly seismic lineaments. The two tectonic regimes may be simultaneously active at different depths separated by an incompetent layer. A set of steeply dipping faults, either parallel or perpendicular to the IKSZ, is active in the region between the HTS and the IKSZ. Seventeen composite fault plane solutions show a predominant pattern of either reverse or strike slip faulting with the inferred slip vectors oriented such that north-south compressional stresses are relieved. Such a stress field is compatible with the north-south convergence between the Indian and Eurasian plates inferred from plate tectonics.

2.1-2 Scholz, C. H. and Kato, T., **The behavior of a convergent plate boundary: crustal deformation in the South Kanto district, Japan,** *Journal of Geophysical Research,* 83, *B2,* Paper 7B0927, Feb. 10, 1978, 783-797.

The northwesternmost part of the Sagami trough, a part of the Philippine Sea-Eurasian plate boundary, was ruptured during the great South Kanto earthquake in 1923. Extensive and frequent geodetic measurements of crustal deformation have been made in the South Kanto district since the 1890s, and these constitute the world's most complete data set on crustal movements. The data, which were reanalyzed and interpreted, indicate the following sequence of events. The coseismic movements resulted from oblique thrust and right lateral slip of about 8 m on a fault outcropping at the base of the Sagami trough. This was followed by postseismic deformation resulting from reversed afterslip of 20 to 60 cm that occurred at an exponentially decaying rate. The interseismic deformation is produced by steady subduction at a rate of about 1.8 cm yr^{-1}. During subduction, the top 10 to 15 km of the plate boundary is apparently locked, while deeper parts slip aseismically at an irregular rate. No significant precursory deformation was observed. The recurrence time for earthquakes of the 1923 type is 200 to 300 yr. The Boso and Miura peninsulas are broken into a series of fault-bound blocks that move semi-independently of the surrounding region. The subduction zone itself, where it is exposed on land, is shown to be wide, encompassing several faults that are active at different times.

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● 2.1-3 Brown, L. D., **Recent vertical crustal movement along the east coast of the United States,** *Tectonophysics,* 44, *1-4,* Jan. 10, 1978, 205–231.

The first detailed profile of apparent vertical crustal movement along the east coast of the United States, extending from Calais, Maine, to Key West, Florida, has been produced from the results of precise leveling by the National Geodetic Survey. Comparison of this profile with one obtained from secular trends in sea level reveals a serious systematic disagreement between the two methods, as large as 19 mm/yr. Estimates of normal measurement error can account for some, but not all, of the misclosures indicated. Thus, at least one of the methods must be seriously affected by some systematic nontectonic influence. The cause of the discrepancy is presently unknown, but the comparisons presented in this paper make possible an estimate of its magnitude, an important step toward identification of the cause and elimination of its effect.

The two data sets have been adjusted using different assumptions as to the source of their disagreement to produce several possible versions of a crustal movement profile along the east coast. Comparison of these profiles with topography, gravity, and seismicity indicate some weak correlations. However, there are several striking correspondences between apparent movements and tectonic and geomorphic features on a regional scale; in particular, the Connecticut Valley graben, the Chesapeake embayment, the Cape Fear arch, and the Cape Canaveral prominence correspond to marked changes in the crustal movement profile. These correlations persist in all of the adjustments, and it is unlikely that they can be attributed to chance. The implication is, therefore, that these four features are active elements in the contemporary tectonic fabric of the eastern United States.

2.1-4 Walcott, R. I., **Geodetic strains and large earthquakes in the axial tectonic belt of North Island, New Zealand,** *Journal of Geophysical Research,* 83, *B9,* Sept. 10, 1978, 4419–4429.

The axial tectonic belt is a belt of active deformation within the boundary zone between the Indian and Pacific plates which crosses North Island and South Island between subduction zones northeast and southwest of New Zealand. Shear strains determined from triangulation data within the axial tectonic belt on the east coast of North Island show variations in rate and direction that are related to the great 1931 earthquake of Hawke's Bay (province around Hawke Bay). This earthquake was associated with thrusting on a fault parallel to the axial tectonic belt and involved a shortening of about 2-3 m. Before the earthquake, shear strains showed a large component of compression normal to the belt and, after, a large component of extension. The Pacific plate is being subducted beneath the axial tectonic belt of North Island along a shallow dipping (about 12°) thrust some 250 km wide from the trench to where the plate abruptly bends and plunges into the asthenosphere. It is suggested that (1) the compressional stage results from locking of the subduction thrust with plate movement accumulating as an elastic strain, (2) the earthquake is caused by rupturing of the locked zone, and (3) the following extension is a relaxation and gravitational spreading within the lithosphere above the thrust. In southern North Island, an extension phase normal to the axial tectonic belt occurred up to about 1920; since that time, compression has been occurring. The onset of compression is believed to mark the locking of the subduction zone. Sufficient time has elapsed for the accumulated strain to be large enough to cause a major earthquake.

● 2.1-5 Herd, D. G., **Neotectonic framework of central coastal California and its implications to microzonation of the San Francisco Bay region,** *Proceedings of the Second International Conference on Micrözonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 231–240.

Microzonation of the San Francisco Bay region must consider future earthquakes on several major northwest-trending faults. Principal among these, the San Andreas fault zone extends through the central Coast Ranges to San Francisco and then north along the Pacific coastline. Paralleling it offshore to the west is the San Gregorio-Hosgri fault system, which joins with the San Andreas near San Francisco. At Hollister, the Hayward-Lake Mountain fault system branches eastward from the San Andreas, extending north beyond Eureka. The Calaveras-Sunol, Concord, and Green Valley faults form a line that splays from the Hayward-Lake Mountain fault system near San Jose. East of San Francisco, the San Joaquin fault zone bounds the east flank of the Coast Ranges. Large earthquakes ($M \geq 7$) are credible on several fault zones in the San Francisco Bay area, and a few have a basic recurrence of tens to hundreds of years.

● 2.1-6 Kisslinger, C., **Seismicity and global tectonics as a framework for microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 3–25.

Improved and more widely deployed seismographs, along with good computational facilities and better methods for treating complex velocity structure, have led to more nearly complete detection and more accurate location of earthquakes. Seismic zones, especially at active oceanic plate margins, have been clearly defined. However, seismicity along plate boundaries within continents is more diffuse, and the boundaries are not clearly delineated. Tectogenesis in plate interiors is a major unresolved problem. Regional seismograph networks are contributing important detailed information concerning concentrations of

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activity, including delineation of linear trends where faults are not readily mappable. The location of accurate hypocenters has led to the development of the concept of seismic gap. The identification of gaps with a high potential for a large earthquake is an important contribution to hazards assessment. The determination of the stress levels along seismic belts, especially within gaps, can help in the evaluation of the seismogenic potential of a particular location. New techniques based on an interpretation of the spectral properties of the seismic signals offer a feasible approach to stress determination. Changes in temporal and spatial patterns of seismic activity may be precursors of impending large earthquakes.

● **2.1-7** Page, W. D. *et al.*, **Seismic hazards along the Makran Coast of Iran and Pakistan: the importance of regional tectonics and geologic assessment,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 669–679.

The available record of historical seismicity along the Makran Coast of Iran and Pakistan is limited and indicates scattered seismic activity east of the Iran-Pakistan border. If only the Iranian portion of the Makran Coast is considered, the seismic hazard, based on interpretation of the historical record, may be incorrectly assessed as low. A more accurate analysis of the seismic hazard must include consideration of the regional tectonic framework in combination with the historical record of seismicity and geologic evidence of tectonic activity.

An assessment of the regional geology and tectonics along the Makran Coast indicates two tectonic regions. The west Makran Coast is characterized by Quaternary units displaced by thrust faults of the Zendan fault system. The south Makran Coast lies shoreward of an active subduction zone characterized by a trench, an emerging coast, deformed sedimentary rock, and active volcanoes inland from the coast. The Nov. 27, 1945, earthquake (M_s 8.3) near Pasni, Pakistan, is related to the near-coast subduction zone, and field investigations have documented 1 to 3 m uplift of the coast at Ormara, Pakistan. The coast at Ormara has raised marine terraces and beaches, and similar raised terraces are found on the headlands along the entire Makran Coast from Karachi, Pakistan, to Jask, Iran. At Konarak, Iran, where raised beaches were examined in some detail, nine terraces were observed. The two lowest terraces at Konarak occur as small remnants, and radiocarbon dates indicate they are Holocene in age.

Quaternary faults of the Zendan fault system are estimated to have earthquakes of magnitudes as large as 7.5. The raised marine terraces and other geologic evidence of the subduction zone indicate that the emergence of the Makran Coast is probably associated with major earthquakes and that major earthquakes can be expected in the future along the entire active coastline from Karachi to Jask. This example illustrates the importance of assessing the tectonic framework and the regional geology and reevaluating the locations of historical earthquakes in the region as part of a realistic assessment of seismic hazards.

● **2.1-8** Bennett, J. H., **Crustal movement on the Foothills fault system near Auburn, California,** *California Geology,* **31,** *8,* Aug. 1978, 177–182.

● **2.1-9** Shimazaki, K., **Correlation between intraplate seismicity and interplate earthquakes in Tohoku, northeast Japan,** *Bulletin of the Seismological Society of America,* **68,** *1,* Feb. 1978, 181–192.

All of the active periods of intraplate earthquakes for the past 100 yr in Tohoku, northeast Japan, correlate with the occurrence of great interplate earthquakes along the Japan trench. The seismically active periods are preceded by a period of quiescence lasting 10 to 15 yr. One-fourth of intraplate earthquakes of magnitude 5.8 and above preceded interplate earthquakes by less than 5 yr; an additional one-half followed them by less than 10 yr. All foreshocks and aftershocks are excluded in these statistics. The duration of the high seismic activity in Tohoku before interplate earthquakes is about one-tenth of that in southwest Japan before interplate earthquakes along the Nankai trough. If the preseismic activity is triggered by an increase in the regional tectonic stress before a great interplate earthquake, the short duration of the activity found in Tohoku suggests a slow rate of earthquake strain accumulation, conformable to geomorphological studies of active faults in Tohoku. The postseismic activity is probably at least in part a result of stress concentration near the base of the interface between the oceanic and continental plates.

2.1-10 Ryan, J. M. W. and Scholz, C. H., **Seismotectonics of the Arthur's Pass region, South Island, New Zealand,** *Geological Society of America Bulletin,* **89,** *9,* Sept. 1978, 1373–1388.

The spatial distribution of the seismicity of the Arthur's Pass region in South Island, New Zealand, shows that earthquakes occur within the crust in definite subparallel zones, each with an east-northeast trend. Composite focal mechanism solutions indicate that the compressive axis is oriented approximately west-northwest, with an average slip direction of N72°E. Comparisons between the 1973 study described here and one conducted in 1972 reveal no differences in the spatial and temporal distributions of the seismicity. Tectonically, the region can be considered as one in which transference of motion between the Alpine fault and the Hikurangi trench is occurring. This tectonic situation, coupled with the shoaling of the Benioff zone associated with a southward migration of the Hikurangi

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trench, suggests that the deformation in the Arthur's Pass region has occurred within the past 2 m.y. This region has marked similarities with the Transverse Ranges area of the San Andreas fault zone in southern California. Both regions are located where two different tectonic and seismic "styles" merge—namely, when a master fault, with its seismic activity of infrequent great earthquakes separated by long periods of quiescence, branches into a system of splay faults having a moderate to high level of continuous activity, with the occurrence of large earthquakes. The regions do differ, however, in that the long quiet zone on the Alpine fault is oblique to the slip vector between plates; whereas similar zones of the San Andreas fault are both parallel and nonparallel to the slip vector. This suggests that long quiet zones of strike-slip faults are not solely a consequence of the orientation of a fault with respect to the direction of relative motion between plates.

● **2.1-11** Mohr, P., Girnius, A. and Rolff, J., **Present-day strain rates at the northern end of the Ethiopian rift valley,** *Tectonophysics,* **44,** *1-4,* Jan. 10, 1978, 141–160.

Five successive geodimeter surveys during a five yr period yield hints as to the manner and rate of crustal extension in the Ethiopian rift valley. The northern geodimeter network traverses an en-echelon offset in the Wonji fault belt at latitude 8°30′N; this belt comprises the youngest volcanism and faulting of the rift floor. The northern network surveys reveal progressive rift extension at mean rates of 3 to 5 mm/yr and strain rates of 6 to 16 x 10^{-7}/yr, essentially confined with the Wonji fault belt segments. Small longitudinal motions of persistent dextral sense have occurred in the intervening zone between the offset segments. It is too early to say whether these deformations are local, regional, or plate-tectonic phenomena, but the present aseismicity of the rift suggests the buildup of regional strain.

● **2.1-12** Buschbach, T. C., **New Madrid seismotectonic study—activities during fiscal year 1978,** Illinois State Geological Survey, Urbana, Illinois, Oct. 1978, 129.

Aeromagnetic survey results were integrated with data gathered previously in adjacent areas. Gravity surveys were made in Kentucky and Indiana and gravimetrically tied to the national network. Preliminary Bouguer gravity maps were made. A 150 km seismic refraction line along the Wabash Valley fault system was monitored. Geologic studies were begun in the Wabash River area where seven seismic stations were installed and in operation. Surface geologic mapping located faulting in Tertiary sediments of the Missouri bootheel.

Fossils of Middle Cambrian age, found in western Kentucky, correlate with Conasuaga strata of the eastern U.S. and represent the oldest sedimentary rocks in the study area. A broad expanse of fine elastic sediments, possibly pre-late Cambrian, is indicated in the Pascola arch below the Cretaceous strata. Studies suggest that faulting is not continuous along the base of the Tiptonville scarp as was previously indicated by trenching. Data have been provided to prepare preliminary maps that show rock types and Precambrian basement configuration.

● **2.1-13** Solonenko, V. P., **Seismotectonics of the Baikal rift zone,** *Tectonophysics,* **45,** *1,* Jan. 17, 1978, 61-69. (Paper presented at Symposium on the Rift Zones of the Earth, Sept. 1975, Irkutsk, U.S.S.R.)

High seismicity in the Baikal rift zone is controlled by the development of conjugately rising and subsiding block structures. Many types of seismological phenomena resulting from large earthquakes are manifested in the rift zone. These phenomena include seismotectonic (regional, zonal, and local), gravity-seismotectonic, and seismogravitational deformations. Impulsive, as distinct from gradual, seismogenetic crustal movements play a dominant role in the recent development of the Baikal geomorphology.

● **2.1-14** Kolmogorov, V. G. and Kolmogorova, P. P., **Some results from studying recent crustal movements in the Baikal rift zone,** *Tectonophysics,* **45,** *1,* Jan. 17, 1978, 101–105. (Paper presented at Symposium on the Rift Zones of the Earth, Sept. 1975, Irkutsk, U.S.S.R.)

Data from previously established first-order (highly precise) and second-order (precise) relevellings, added to the line of relevellings performed by the Inst. of Geology and Geophysics (U.S.S.R. Academy of Sciences) during the last decade, serve as a basis for the first schematic map of recent vertical deformation rates in the Baikal rift zone. This paper briefly describes some results of an analysis of geodetic and geophysical surveys carried out to quantify the recent tectonic development of the Baikal rift system and determine qualitative and quantitative relations between seismicity and recent crustal movements.

2.1-15 McHugh, S. and Johnston, M. J. S., **An analysis of coseismic tilt changes from an array in central California,** *Journal of Geophysical Research,* **82,** *36,* Dec. 10, 1977, 5692–5698.

Local earthquakes with magnitudes of greater than or nearly equal to 2.5 and within 20-50 km of tiltmeters along the San Andreas fault typically generate offsets in tilt, tilt seismograms, and impulsive tilt behavior at the time of the earthquake. The amplitudes and azimuths of the coseismic tilt offsets from local earthquakes observed at a small array of four instruments approximately 30 km south of Hollister, California, are compared to the amplitudes and azimuths predicted by a rectangular source, elastic halfspace dislocation model. Almost all observed coseismic offset amplitudes are 1-3 orders of magnitude larger than the predicted amplitudes. The predicted offset azimuths also are not in

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agreement with the observed azimuths. There is neither a uniform method of scaling the predicted amplitudes nor a constant rotation that may be applied to the predicted azimuths that will consistently reproduce the observed offsets. Errors in hypocenter location and fault plane orientation are not sufficient to explain the discrepancies between observations and predictions. Similar results occur for teleseismic earthquakes. A lack of agreement in the observed offset amplitudes across the array indicates that tilt changes are triggered at or near the instrument site by the passage of seismic waves. No significant agreement was obtained between the direction of coseismic tilts and either the secular tilt trends or local geologic features. Triggered movement on near-surface cracks, fractures, and minor faults appears the most viable physical explanation for the observed offsets. Short-base-line near-surface tiltmeters appear inadequate for measuring tilt displacement fields generated by local earthquakes. Deep borehole installations appear necessary for this measurement. Coseismic tilt transients appear to be caused by seismically induced water table perturbations near the tiltmeter site.

● **2.1-16** Carraro, F. and Polino, R., **Geological and morphological phenomena caused by high seismicity as a natural source of information on recent seismicity,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 54-59. (For a full bibliographic citation, see Abstract No. 1.2-7.)

It is well known that a high degree of seismicity leads to geological and morphological phenomena in meizoseismal areas. The parameters of some of these phenomena, such as rockfalls, earthquake cracks, surface faulting, sedimentary dikes, and changes in hydrographic networks, are examined. It is recommended that surveys of these phenomena be conducted both in highly seismic areas to gather supplemental information and in areas with a recent history of intense geodynamic activity but no history of seismic activity.

● **2.1-17** Harrison, J. C., DeMay, J. M. and Meertens, C., **Tiltmeter results from Adak,** *Stress and Strain Measurements Related to Earthquake Prediction,* 162-175. (For a full bibliographic citation, see Abstract 1.2-14.)

Tilt has been measured on Adak, in the Aleutian Islands, since the summer of 1975 in an attempt to establish a correlation between the occurrence of earthquakes and a supposed precursory tilting of the ground. The problem involves (1) establishing the nature and size of the assumed precursory tilts, and (2) devising a way of installing and operating a network of tiltmeters capable of observing these tilts under the constraints imposed by the Aleutian conditions.

● **2.1-18** Ogniben, L., **The broad geodynamical frame of Friulian seismicity,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 25-37. (For a full bibliographic citation, see Abstract No. 1.2-7.)

● **2.1-19** Slater, L. E., **Crustal deformation and aseismic fault slip near Hollister, California,** *Stress and Strain Measurements Related to Earthquake Prediction,* 502-520. (For a full bibliographic citation, see Abstract 1.2-14.)

● **2.1-20** Pratt, H. R. and Hardin, E. H., **The Terra Tek stress monitoring system: theory, calibration and data from the Palmdale area, California and Salt Lake City, Utah,** *Stress and Strain Measurements Related to Earthquake Prediction,* 393-424. (For a full bibliographic citation, see Abstract 1.2-14.)

A flatjack stress-monitoring system is discussed. The system measures temporal changes in stress in three flatjacks oriented at 120° to each other, thus enabling the horizontal stress field to be resolved. Temporal stress data are presented from the Little Rock site near Palmdale, California, and from the Little Cottonwood Canyon site near Salt Lake City, Utah. Earthtides are easily recognizable as background data, indicating the sensitivity of the system. The development of a borehole stressmeter using the same flatjack configuration is discussed and calibration data are presented. More development is required for the borehole stress-monitoring system.

● **2.1-21** Mortensen, C. E., **The analysis of tiltmeter data,** *Stress and Strain Measurements Related to Earthquake Prediction,* 364-392. (For a full bibliographic citation, see Abstract 1.2-14.)

Tilt data for periods as great as five years from 30 shallow borehole tiltmeter sites within the U.S. Geological Survey central and southern California tiltmeter networks are characterized, and examples of the data are presented. Long-term secular tilt rates range from 0.5 to 50 or more μradians per year with typical values ranging between 5 and 20 μradians per year. Tests at the San Francisco Presidio vault and comparison of tilt measurements at the Presidio and Berkeley vaults with tilt measurements from shallow borehole tiltmeters along active sections of the San Andreas and other faults suggest that it should be possible to measure long-term tilt with stability on the order of 1 μradians per year with the shallow borehole installations at sites with favorable local geologic and topographic conditions and with careful emplacement procedure.

Noise level and response to various sources of spurious signals vary widely for different period ranges and for different sites and appear to be highly dependent on local site conditions. The dominant sources of noise result from meteorological effects acting at the earth's surface and the

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instrument-earth interface and local geology and topography. Mechanical and electrical stability of the instrument, stability of the instrument-earth interface, data processing errors, and other problems can also contribute spurious signals. Clusters of instruments at varying distances and depths, comparison of instruments with different baselines, and comparison with leveling results offer some possible techniques for isolating responses to various noise sources. Preliminary results of the application of some of these techniques suggest that some short-period signals decrease in amplitude with depth.

● 2.1-22 Morrissey, S.-T. and Stauder, W., **Tiltmeter research at New Madrid and at Adak: the stability and reliability of shallow bore-hole tiltmeters**, *Stress and Strain Measurements Related to Earthquake Prediction*, 348-363. (For a full bibliographic citation, see Abstract 1.2-14.)

● **2.1-23** Johnston, M. J. S., Smith, B. E. and Mueller, R. M., **Measurements of local magnetic field, observations of fault creep, and local earthquakes on the San Andreas fault, California**, *Stress and Strain Measurements Related to Earthquake Prediction*, 244-260G. (For a full bibliographic citation, see Abstract 1.2-14. This report was also published as *Local magnetic field measurements, fault creep observations and local earthquakes on the San Andreas fault*, Open-File Report 78-809, U.S. Geological Survey, Menlo Park, California, 1978.)

Simultaneous records of local variations in magnetic field, fault creep, and the occurrence times of local earthquakes have been obtained for the period from early 1974 through mid-1977 along the San Andreas fault between the most southern extent of the 1906 earthquake fault break and the most northern extent of the 1857 break. The data utilized are primarily from stations located near the two ends of this section of the fault, where strain accumulation is expected. The magnetic data show that local magnetic field variations up to 1.8 gammas with durations of a few minutes to several months have occurred. The creep data indicate both episodic events and changes in creep rate of up to 10 mm/yr lasting for six months or more. No clear magnetic transients or offsets are evident, either simultaneous with or preceding the occurrence times of the episodic creep events by up to a day or so. Although some patterns of creep onset times at adjacent stations appear to correspond to some periods of longer-term changes in the local magnetic field, these changes do not always occur, and other groups of creep events have no corresponding changes in the local magnetic field. Earthquakes with magnitudes less than 4.0 do not appear to correspond in time to local changes in the magnetic field greater than 0.8 gamma or variations in the creep rate.

In order to explain the observations presented in this study, it appears necessary to allow for a substantial amount of deep aseismic slip, without any obvious attendant changes in the time distribution or size of the local earthquakes. Changes in stress related to the surface expression of aseismic slip on the San Andreas fault can be estimated from dislocation models fitted to these data and to observations of simultaneous strains and tilts at points near the fault. These stress values are on the average less than one bar near the surface but are probably more than 10 bars in localized regions at depths of approximately one kilometer.

● 2.1-24 Isacks, B. L. *et al.*, **Measurements of tilt in the New Hebrides Island arc**, *Stress and Strain Measurements Related to Earthquake Prediction*, 176-221. (For a full bibliographic citation, see Abstract 1.2-14.)

● **2.1-25** Fett, J. D., **Periodic high precision gravity observations in southern California**, *Stress and Strain Measurements Related to Earthquake Prediction*, 158-161. (For a full bibliographic citation, see Abstract 1.2-14.)

Two networks of permanent gravity stations have been established in southern California. Establishment of the first network began in late 1975. It is observed semiannually in January and July. The network includes approximately 130 stations and consists of permanent benchmarks widely spaced along eight lines normal to the major fault zones. A small portion of the area influenced by the San Andreas fault is covered by the network, and a major portion of the area influenced by the San Jacinto fault and Elsinore fault is covered. The second network was established in Oct. 1976. It is monitored monthly. It consists of 86 stations along seven lines crossing and approximately normal to the San Andreas fault. The goal of the research is to help develop an economical and reliable method for monitoring elevation or density changes that might be precursors to earthquakes.

● **2.1-26** Searls, C. A. *et al.*, **Total field measurements on the San Andreas fault near Gorman, California**, *Stress and Strain Measurements Related to Earthquake Prediction*, 103-127. (For a full bibliographic citation, see Abstract 1.2-14.)

This paper discusses the planned establishment of five continuously recording magnetic observatories in the northwestern San Gabriel Mountains near Gorman, California. The observatories form a two-dimensional array adjacent to a magnetic high in the vicinity of the junction of the San Andreas and Garlock faults.

● 2.1-27 Clark, B. R., **Progress in monitoring stress changes near active faults in southern California**, *Stress and Strain Measurements Related to Earthquake Prediction*,

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84–102. (For a full bibliographic citation, see Abstract 1.2–14.)

Results obtained from recording stress levels in the stressmeter net around Palmdale indicate that local horizontal stresses are changing in a reasonably systematic way. In a six-month period from Nov. 1977 through Apr. 1978, three of the sites showed an increase in compressive stress in the northeast-southwest direction. The fourth site, near Valyermo, coincides with the area of the earthquake swarm of 1976-77; it showed an increase in stresses in all directions. The fifth site, southeast of the earthquake swarm, was extremely quiet.

The lack of major earthquake activity in the net has made it difficult to establish that the instruments are measuring real tectonic stress changes. However, indirect arguments suggest that the data are real: the changes are consistent at three widely spaced sites, they do not correspond to any instrument drift patterns in laboratory tests, and they are not consistent with any predicted nontectonic effects. If the changes are real and are caused by tectonic changes at depth, then the magnitude of the changes supports the contention that, at least for short-term fluctuations, the coupling between tectonic stresses at depth and near the ground surface is quite good. Consequently, the near-surface measurements have potential application as an independent measure of at least local seismic stress drops. More important, the prognosis for use of the instrumentation for detecting stress precursors to earthquakes is very favorable. It appears that the measurements are at approximately the correct sensitivity and that the noise level is low.

● **2.1-28** Bilham, R. and Beavan, J., **Tilt measurements on a small tropical island,** *Stress and Strain Measurements Related to Earthquake Prediction,* 33–45. (For a full bibliographic citation, see Abstract 1.2–14.)

Tilt measurements were made on the Caribbean island of Anegada (18°44′N, 64°25′W) using precision levelling, sea-level measurements, and an array of borehole tiltmeters. The tiltmeter measurements after two years of undisturbed operation indicate a tilt rate of approximately a microradian per month, whereas the precision leveling indicates that the island is stable to within a microradian per year (1976-1978). Variations in sea level appear to affect the tiltmeters coherently, although tidal tilts vary significantly over 400 m distances.

● **2.1-29** Berger, J. and Wyatt, F., **Some remarks on the base length of tilt and strain measurements,** *Stress and Strain Measurements Related to Earthquake Prediction,* 3–32. (For a full bibliographic citation, see Abstract 1.2–14.)

2.1-30 Matsuda, T. *et al.*, **Fault mechanism and recurrence time of major earthquakes in southern Kanto district, Japan, as deduced from coastal terrace data,** *Geological Society of America Bulletin,* **89,** *11,* Nov. 1978, 1610–1618.

The southern Kanto region has had two shocks of magnitude 8 or greater during the past 1000 yr. They were the 1703 and 1923 earthquakes, which occurred along the Sagami trough, a northeastern boundary of the Philippine Sea crustal plate in contact with the Asian plate. Although they occurred in nearly the same region, the 1703 earthquake was significantly different from the 1923 earthquake in the distribution of coastal uplift and tsunami height. The 1703 earthquake deformation is described on the basis of the height of the marine terraces along the coast of the southern Kanto region.

The 1703 earthquake is interpreted, as is the 1923 earthquake, as the result of low-angle, right-lateral faulting with a thrust component at the plate boundary. However, the fault surface in 1703 was longer (about 200 km) and was located farther east than that of the 1923 earthquake. On the basis of the pattern of coastal uplift and the trend of the Sagami trough, the fault surface of the 1703 earthquake can be divided into three planes, which involve the eastern part of the source region of the 1923 earthquake to the west (plane A), the Kamogawa submarine cliff in the middle (plane B), and a segment near the source region of the 1953 Boso-oki earthquake (M=8.0) to the east (plane C).

The Boso and Miura peninsulas in the southern Kanto region have been uplifted during at least the last 6000 yr, and major uplifts have been accompanied by earthquakes like those of 1703 and 1923 many times. The recurrence time of similar uplifts is estimated at 800 to 1500 yr, on the basis of the numbers of the uplifted Holocene terraces in the Boso Peninsula, the rate of upheaval during the last 6000 yr, and the present geodetic data. Thus, it is unlikely that major earthquakes such as the 1703 and 1923 earthquakes will occur in the same segments in the near future. The Oiso area, however, which is located west of the western end of the 1703 faulting, seems higher in seismic risk than the other parts of the Sagami trough fault, because the sum of the recent uplift in the 1703 and 1923 earthquakes in that area is significantly less than the average rate of uplift there during the past 6000 yr.

2.1-31 Ni, J. and York, J. E., **Late Cenozoic tectonics of the Tibetan plateau,** *Journal of Geophysical Research,* 83, *B11,* Nov. 10, 1978, 5377–5384.

Normal faulting interpreted from Landsat imagery and fault plane solutions of earthquakes suggests late Cenozoic east-west extension in the Tibetan plateau. Volcanism and

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earthquake swarms could be additional evidence for extension, although they are not unique to extensional environments. Normal faulting contrasts with major thrusting along the southern boundary and major strike-slip faulting near the other boundaries of Tibet. The extension may be related to western Tibet being compressed between thrusting on the south and strike-slip faulting on the northwest and consequently spreading along an east-west trend.

2.1-32 Goulty, N. R. and Gilman, R., **Repeated creep events on the San Andreas fault near Parkfield, California, recorded by a strainmeter array,** *Journal of Geophysical Research,* 83, *B11,* Nov. 10, 1978, 5415–5419.

Following the 1966 Parkfield-Cholame (California) earthquakes, a creepmeter was installed across the fresh surface break of the San Andreas fault at Carr Ranch (now part of the Jack Ranch), 10 km southeast of Parkfield. It has recorded continuing slip which, since the end of 1968, has occurred at about 10 mm yr^{-1}, primarily in discrete events at intervals of a few months. In April 1976, an array of four strainmeters was installed near this creepmeter at distances between 0.2 and 2.2 km from the fault to detect the elastic strain fields associated with creep events on the fault. Four similar sets of signals have since been observed on the strainmeter array, separated by intervals of 4 to 5 months. A week after three of these events, creep began at the Carr Ranch creepmeter, but no signals were detected by the strainmeters while the creepmeter was recording slip. Analysis of the strainmeter signals shows that they can be modeled by a slip zone on the fault 640 m long and extending from 30 to 510 m in depth, with right lateral slip of about 3.5 mm. Propagation of a dislocation from the lower northwest corner of the slip zone to the upper southeast corner is indicated. The phenomenon may be due to an asperity or an area of higher friction on the fault at Carr Ranch, which is repeatedly loaded to failure by steady slip on the fault around it. This is the first report of a well-defined fault creep event which repeats itself with a high degree of similarity and which has been observed at a distance of over 2 km from the fault.

● 2.1-33 Yamashina, K., **Induced earthquakes in the Izu Peninsula by the Izu-Hanto-oki earthquake of 1974, Japan,** *Tectonophysics,* 51, *3/4,* Dec. 20, 1978, 139–154.

Recently, small earthquakes in the Izu Peninsula in central Japan have occurred in a region where differential strain, or shear strain on the nodal planes, may have been enhanced by the Izu-Hanto-oki earthquake of 1974 (M = 6.9 after JMA). It is suggested that the seismic activity was induced by the redistribution of strain accompanying the Izu-Hanto-oki earthquake. The activity from Aug. 1975 may have also been affected by an abnormal uplift in the northeastern part of the peninsula. Based on plausible models, the uplift caused the accumulation of differential strain in the focal region of the subsequent earthquakes. This change of crustal strain was of the order of 10^{-6}, ten times as much as the average annual accumulation. Consequently, the sudden or rapid change of strain was likely to have played an essential role in the subsequent seismic activity. This effect could be one of the factors which trigger a shallow intraplate earthquake.

2.2 Wave Propagation

● 2.2-1 Kern, H., **The effect of high temperature and high confining pressure on compressional wave velocities in quartz-bearing and quartz-free igneous and metamorphic rocks,** *Tectonophysics,* 44, *1-4,* Jan. 10, 1978, 185–203.

Compressional wave velocities were measured in granite, granulite, amphibolite, and peridotite specimens under conditions of high temperature up to 700°C and confining pressures up to 6 kbar. It was found that, in general, velocity increases with pressure and decreases with temperature. Quartz-bearing rocks show an anomalous behavior in their compressional wave velocities. The velocity-temperature relations exhibit a velocity-"deep" because of the high-low inversion of the constituent quartz crystals. The intrinsic effect of temperature on velocities is hard to determine because of thermal expansion and consequent loosening of the structure. The opening of new cracks and the widening of old cracks causes a large decrease in compressional wave velocities. The minimum pressure to prevent damage at a given temperature should, therefore, be about 1 kbar/100°C.

The values obtained at these conditions are considered to be most nearly correct as intrinsic properties of the compact aggregates. Velocity anisotropies at high confining pressures and high temperatures correlate with the preferred lattice orientation of the constituent minerals. The effect of dimensional orientation and microcracks on seismic anisotropy seems to be of minor importance in dry rocks. The higher the confining pressure, the more it is eliminated. The data do not support the concept of a velocity maximum in depths of 10 to 20 km.

● 2.2-2 Kudo, K., **The contribution of Love waves to strong ground motions,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 765–776.

Love waves, whose characteristics are mostly controlled by thick (2-3 km) sedimentary layers, were calculated using normal mode theory for given fault parameters of the Off-Izu Peninsula earthquake (1974), the north Izu earthquake (1930), and the Saitama earthquake (1931). These were compared with the transversely polarized displacements observed at Hongo, Tokyo. Good agreement between synthetic and observed seismograms was obtained in both amplitude and phase in the period range from 5 to 10

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or more sec. Far-field expressions derived from normal mode theory are sufficient for the prediction of Love waves when kr is larger than 10, where k and r are wave number and epicentral distance, respectively. For waves with periods greater than about 10 sec, this condition is fulfilled for epicentral distances larger than 40 km for the structure in and around Tokyo. A point force approximation is adequate but a slight improvement is obtained by evaluating a fault of finite vertical extent.

● **2.2-3** Nuttli, O. W., **A time-domain study of the attenuation of 10-Hz waves in the New Madrid seismic zone,** *Bulletin of the Seismological Society of America,* **68,** 2, Apr. 1978, 343–355.

From a time-domain study, the amplitude of 10-Hz P waves in the New Madrid seismic zone was found to fall off as the inverse 1.4 power of the epicentral distance. The amplitude of 10-Hz Lg waves was found to decay as for an Airy phase with a coefficient of anelastic attenuation of 0.006km^{-1}. In almost all cases, the Lg motion was found to be larger than that of P, even at epicentral distances of 5 km and less. Thus, design earthquake motions need to be concerned with Lg waves, whose coda also have longer duration than those of the P waves. The apparent Q for the 10-Hz Lg waves is 1500, identical to that found previously by Nuttli for higher mode 1-Hz Lg waves. The attenuation of 10-Hz Lg waves is sufficiently small that one must pay attention to their damage potential at distances as large as a few hundred kilometers.

● **2.2-4** Nuttli, O. W. and Dwyer, J. J., **Attenuation of high-frequency seismic waves in the central Mississippi Valley,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 10,* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, July 1978, 75.

This study is concerned with the attenuation of high-frequency earthquake waves in the central Mississippi Valley. The data were obtained from seismographs which measured the vertical component of ground motion. Recordings were made on analog magnetic tape and on 16-mm photographic film. Most attention was devoted to a study of Lg waves, which are higher mode surface waves that produce the largest ground motion. At frequencies of 1 to 10 Hz the specific dissipation factor Q of the Lg waves was found to be 1500. The corresponding coefficient of anelastic attenuation is 0.0006 km^{-1} for 1-Hz waves and 0.006 km^{-1} for 10-Hz waves. Other investigators have found Q for tectonic areas such as California to be 200 to 250, which implies that the value of the coefficient of anelastic attenuation in those regions is almost ten times greater than in the central Mississippi Valley. The results of the present study indicate that, in the central United States, high-frequency waves will produce significant ground motions at relatively large distances. This is not the case in California nor other tectonic areas. In the frequency domain, the Fourier displacement spectra of the Lg motion showed the typical flat level at the lower frequencies and the rapid fall-off of amplitude with increasing frequency at the high frequencies. In the time domain, on the other hand, the level of ground displacement in the source region was essentially constant between frequencies of 1 to 10 Hz. This fact, together with the relatively low attenuation of the Lg waves, indicates that waves of frequencies as high as 10 Hz may have relatively large amplitudes and accelerations at epicentral distances as large as hundreds of kilometers for central United States earthquakes.

● **2.2-5** Kumbasar, N., **Wave propagation in periodically layered media and its application to earthquake spectra,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-01, 1978, 1–7.

It has been shown that wave propagation in periodically layered media shows specific properties. In the case of steady-state oscillations, wave velocities corresponding to some frequencies may differ distinctly from the average velocity, and the medium may be opaque for other frequencies. In this paper, the characteristics of periodically layered media are represented by a Fourier expansion, and the wave equation is transformed into a differential equation with periodic constants. The wave velocity and the characteristic exponent that determine the attenuation arising from reflections are found using the Hill determinant, which is obtained from the solution of the differential equation. The same method also is applied to the shear wave propagation in soils with many nonperiodic layers to investigate the presence of attenuation or opaqueness.

● **2.2-6** Caloi, P. and Migani, M., **Influence of the local surface strata of the earth crust on the effects of the May 6, 1976 Friuli earthquake,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. I,** 60–86. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Earthquakes of a certain intensity (magnitudes not exceeding 4.0 - 4.5) cause ordinary seismic waves that propagate through a medium as though the medium were continuous. Many such examples were provided in the Friuli area during the 1976 seismic period. However, if an earthquake intensity at the focus can overcome the cohesive forces that hold a faulted surface structure intact, the structure will not act merely as a means of transit for the seismic waves but the structure will react with its own movements, consisting generally of flexural waves; the activity of the flexural waves is then superimposed on the activity of the ordinary seismic waves. It is believed that this is the first paper dealing with the superimposition of such violent movements on ordinary seismic waves. Special reference is made to the catastrophic earthquake that

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occurred on May 6, 1976, in Friuli, where the phenomenon assumed unexpected proportions.

2.2-7 Grady, D. E., Hollenbach, R. E. and Schuler, K. W., **Compression wave studies on calcite rock,** *Journal of Geophysical Research,* 83, *B6,* Paper 8B0201, June 10, 1978, 2839–2849.

Dynamic compression wave studies have been conducted on three calcite rocks, Solenhofen limestone, Oakhall limestone, and Vermont marble, in the stress range of 0 to 5 GPa. Plate impact techniques provided transient stress wave input, and diffuse laser interferometry was used to study the evolution of these pulses through various thicknesses of rock. Both loading response and release wave response were determined from the time-resolved particle velocity profiles. The calcite I-II and II-III phase transitions dramatically influence wave propagation in this stress region. The I-II transition begins between 0.6 and 1.2 GPa, depending on rock type, and is found to be consistent with a reversible, displacive polymorphic phase change. A constitutive model based on stress heterogeneity describes most of the features associated with the I-II transition. The calcite II-III transition proceeds above 2.4 GPa, and peak stress values traverse a metastable Hugoniot. This wave feature and others are more characteristic of a slower, reconstructive phase change. It is concluded that stress wave features reveal striking differences in the nature of the shock-induced calcite transitions and that these transitions strongly influence the dynamic constitutive behavior of calcite rock.

● 2.2-8 Ohnabe, H., **Propagation of waves in fluid-saturated transversely isotropic poroelastic solid,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 157–164.

This paper investigates wave propagation in a fluid-saturated, transversely isotropic solid. Based on Biot's approach to the treatment of an isotropic poroelastic medium, a system of six coupled governing differential equations is derived. The condition of nontrivial solutions of the system gives three frequency equations for a plane harmonic wave propagating along the x-axis and two equations for the z-axis. The relationship of the phase velocity and attenuation coefficients to the frequency for the three types of waves in both cases are found from these equations and are displayed in graphs showing the different elastic coefficients and permeability properties. It is found that an anisotropy of elastic constants and permeability properties affects the phase velocity and attenuation coefficient for P waves more than for S and P_2 waves.

2.3 Source Mechanisms

● 2.3-1 Chrometskaya, H. A. and Shebalin, N. V., **Quantification of past earthquakes,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-01, 1978, 1–8.

A system of parameters describing the seismic source (tree coordinates, size, orientation, magnitude, and seismic moment) is proposed. These parameters are estimated from macroseismic data. A special technique is described for application of the proposed system, and some examples are presented for strong earthquakes in the U.S.S.R.

● 2.3-2 Ebel, J. E., Burdick, L. J. and Stewart, G. S., **The source mechanism of the August 7, 1966 El Golfo earthquake,** *Bulletin of the Seismological Society of America,* 68, *5,* Oct. 1978, 1281–1292.

The El Golfo earthquake of Aug. 7, 1966 (m_b = 6.3, M_S = 6.3) occurred near the mouth of the Colorado River at the northern end of the Gulf of California. Synthetic seismograms for this event were computed for both the body waves and the surface waves to determine the source parameters of the earthquake. The body-wave model indicated a right lateral, strike-slip source with a depth of 10 km and a far-field time function 4 sec in duration. The body-wave moment was computed to be 5.0 x 10^{25} dyne-cm. The surface-wave radiation pattern was found to be consistent with that of the body waves with a surface-wave moment of 6.5 x 10^{25} dyne-cm. The agreement of the two different moments indicates that the earthquake had a simple source about 4 sec long. A comparison of this earthquake source with the Borrego Mountain and Truckee events demonstrates that all three of these earthquakes behaved as high stress-drop events. El Golfo was shown to be different from the low stress-drop, plate-boundary events which were located on the Gibbs fracture zone in 1967 and 1974.

2.3-3 Rial, J. A., **The Caracas, Venezuela, earthquake of July 1967: a multiple-source event,** *Journal of Geophysical Research,* 83, *B11,* Nov. 10, 1978, 5405–5414.

This study of Caribbean plate tectonics first focuses on the determination of fault parameters and source processes of the Caracas, Venezuela, earthquake of July 29, 1967. Synthetic seismograms which closely reproduce the observed *P, SH,* and Love wave seismograms were generated using generalized ray and mode theories. The results indicate a complicated faulting process, consisting of at least three separated sources aligned along a N10°W trending en echelon vertical left lateral strike-slip system of three faults that ruptured from north to south, at three discrete places with an extreme separation of 90 km. The process of rupture progressed southward with a mean velocity of 3 km/s. The focal depths of the individual sources varied

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between 8 and 27.5 km. The total dislocation was calculated as 120 cm along the direction N10°W, and the total average moment as 4 X 10^{26} dyne cm. The multiple character of the event severely constrains the number of suitable source models that can be inferred, thus facilitating the process of inversion. Tectonic implications are briefly discussed, and local geology is successfully invoked to support the source model.

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

2.4-1 Milne, W. G. *et al.*, **Seismicity of western Canada,** *Canadian Journal of Earth Sciences,* **15**, *7*, July 1978, 1170-1193.

The seismicity of western Canada has been studied for 1899-1975. The quality of the data collected improved through this period as the number of recording stations increased and the location and analysis methods developed, but significant uncertainties and biases remain. Although these restrictions limit detailed correlation of seismic events with specific tectonic features, in general the most active earthquake areas correspond to the boundaries between the major lithospheric plates. These are the Queen Charlotte-Fairweather fault system (Pacific-American plates), the offshore ridge-fracture zone system (Pacific-Juan de Fuca plates), and the Vancouver Island-Puget Sound region (Juan de Fuca-American plates). Strain release calculations show that most seismic energy is released along the Queen Charlotte-Fairweather fault system and that a significant accumulation of strain may be available for release as earthquakes in the Vancouver Island-Puget Sound area. Except for the absence of thrust earthquakes along the apparently converging margin, focal mechanisms are in good agreement with the postulated plate motions. The b values in the frequency-magnitude recurrence relation for different areas within the region range from 0.65 to 0.82.

● 2.4-2 Allison, M. L. *et al.*, **Elsinore fault seismicity: the September 13, 1973, Agua Caliente Springs, California, earthquake series,** *Bulletin of the Seismological Society of America,* **68**, *2*, Apr. 1978, 429-440.

A relatively small M_L = 4.8 earthquake and its aftershock series on the southern portion of the Elsinore fault zone in eastern San Diego County, California, provided a rare opportunity to study an area that has been subjected to variable tectonic interpretations in the past. Within 12 to 26 hr after the main shock, a network of four portable seismograph stations was established around the main event near Agua Caliente Springs to supplement the stations of the Southern California Seismographic Network. Four days after the main shock, seven additional portable seismograph stations were installed. In addition to the main event, 45 subsequent events were studied, ranging in magnitude from about 1.0 to 3.7. Of these, 36 could be termed aftershocks by their close proximity to the main event, whose proper location was determined by analysis of the aftershock series. Of the two branches of the Elsinore fault in this region, the southern branch is associated with the earthquake series. Focal mechanisms are consistent with right-lateral strike slip along the southern branch, with northeast dip at latitude 32°51′N. These conclusions are supported by hypocentral locations. Thrust activity on the two fault branches may be developing a horst between them, accounting for elevation and tilt changes observed near Agua Caliente.

● 2.4-3 Lee, W. H. K., Wu, F. T. and Wang, S. C., **A catalog of instrumentally determined earthquakes in China (magnitude ≥6) compiled from various sources,** *Bulletin of the Seismological Society of America,* **68**, *2*, Apr. 1978, 383-398.

A catalog of instrumentally determined earthquakes in China (magnitude ≥6) from 1901 to 1976 has been compiled in a form suitable for computers. The data include the origin time, epicenter, focal depth, magnitude, province where the earthquake occurred, and information sources. The source materials consulted are extensive and include publications in Chinese and Japanese.

● 2.4-4 Gupta, H. K. and Combs, J., **Investigation of isoseismals for some large magnitude earthquakes in China,** *Bulletin of the Seismological Society of America,* **68**, *1*, Feb. 1978, 193-204.

Documented historical records of large-magnitude earthquakes in China, in addition to providing data for preparing catalogs for seismostatistical investigations, have been used by seismologists for constructing isoseismal maps. Isoseismals of earthquakes tend to be influenced by the surficial sedimentary terrain, and, in the case of the historical earthquakes, the ambient population density affected earthquake reporting used in preparing isoseismal maps. However, isoseismal geometry in the epicentral region also reflects the pattern of faulting associated with the earthquake, whether the faults are visible on the surface or not.

Isoseismals for a large number of earthquakes in China have been examined and interpreted. An interesting deduction is the definition of a boundary separating the East China mini-plate from the West China mini-plate which strikes almost north-south between longitudes 102° and 105°E and extends from about 25° to 36°N. Isoseismals on the west of this boundary are elongated from NW to NNW and on the east from NS to NNE. Beginning with 1800 A.D., available isoseismals of all earthquakes of

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magnitude greater than or equal to 6 have been examined for this area. These isoseismal geometries, combined with the inferred left-lateral, strike-slip faulting on satellite imagery, as well as on some recent earthquakes on the western side of the boundary, and the rotation measured by Chinese scientists near the city of Shan Tan during the Feb. 11, 1954, earthquake (38°51′N, 101°22′E, focal depth 12.5 km, M = 7 1/4) are consistent with a clockwise rotation of the West China mini-plate.

● 2.4-5 Ucer, S. B. *et al.*, **Earthquake activity in western Turkey (September–December 1976)** (Bati Turkiye'de deprem etkinligi, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **5**, *19*, Oct. 1977, 45–114.

This report identifies the epicenters of 800 earthquakes which occurred in western Turkey and surrounding areas from September through December 1978. The data were obtained from the 13 seismic stations which form the Kandilli Observatory Network. Specifications related to these stations are given in a table. The data were processed by computer, using the epicenter location program to obtain the origin time, the location of the epicenters, and the magnitude of the earthquakes. In addition to first P arrivals, S arrivals are determined. The Balkan crustal velocity model, prepared at the Bureau Central International de Seismologie, is used in the computation. To determine magnitudes, the recorded signal duration of the events was used. The average of the station magnitudes is adopted as the magnitude value of the earthquake.

The findings are listed chronologically in the text. Included are the origin time, the location of the epicenter and the magnitude class. In addition, the root-mean-square error of the time residuals; the number of stations used in obtaining the location; the solution quality (A, good; B, fair; C, poor); the determinations of other seismological centers, such as the U.S.C.S. and C.S.E.M.; and macroseismic information about the earthquakes are given in this list. Epicenters given in the list are plotted as monthly maps according to magnitude and solution quality. The epicenter distributions in western Turkey for the last four months of 1976 show two areas where high concentration of epicenters are observed, the Emet area and the Izmir-Karaburun area.

● 2.4-6 Adams, R. D., **Principal earthquakes during the year 1977**, *Bulletin of the New Zealand National Society for Earthquake Engineering*, **11**, *1*, Mar. 1978, p. 62.

There were nearly 1,000 earthquakes of Richter magnitude 4 or greater in New Zealand in 1977. The largest shock, which occurred on Jan. 18, had a magnitude of 6.2; it had a shallow focus, located about 25 km east of Cape Campbell. There were several other shallow earthquakes of magnitude 5 or greater. A number of deep earthquakes of magnitudes of approximately 5.6 also occurred.

● 2.4-7 McCue, K. and Papastamatiou, D., **The value of extreme statistics in the assessment of seismic risk**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-07, 1978, 47–51.

The application of extreme value statistics reduces a statistical sample to a set of yearly maxima. The reduced statistical sample may be assembled on the basis of original macro- or microseismic work. The approach is illustrated with an example from Switzerland where the instrumental record does not include magnitude determination. The instrumental recordings were used to determine the yearly maximum magnitudes. In this application, the recorded maxima were converted by use of the instruments to Wood-Anderson readings and then to the corresponding local Richter magnitudes. The statistical distribution is satisfied by a type III distribution (limited size of the members of the population) indicating a regional limiting magnitude of 6.5. The distribution provides the necessary input to the stochastic seismic risk analysis.

● 2.4-8 Bureau, G. J., **A seismic model of northern Anatolia**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-03, 1978, 17–24.

Historical earthquake data are used to develop a seismic model of northern Anatolia. The calculations assume a fault-dependent attenuation of the earthquake motion that corresponds to elliptical iso-acceleration contours. The model is used to develop an expectancy map of peak accelerations.

● 2.4-9 Hattori, S., **A new proposal of the seismic risk map based on the maximum earthquake motions, the ground characteristics and the temporal variations of the seismicity**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 421–432.

A new seismic risk map for Japan is proposed. It combines expectations of the maximum earthquake motion at base rock, ground characteristics, and temporal variations of seismicity. To obtain estimates of the maximum earthquake motion, earthquake data from 1885-1973, Kanai's attenuation model, and Gumbel's asymptotic distribution are used. For ground characteristics, seismic data obtained by strong-motion seismographs of the Japan Meteorological Agency (JMA) are used. The base rock is classified depending on the period range of concern. The temporal variations of seismicity are estimated using cumulative energy curves. The curves are calculated by using earthquakes that occurred within 250 km radius of the site of concern.

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● 2.4-10 Patwardhan, A. S. and Cluff, L. S., **The concept of residual risk in earthquake risk assessments,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 535-546.

The concept of residual risk has application in earthquake risk assessment. Residual risk is a quantitative portion of the calculated risk for a given probability that needs to be managed. It is time dependent, and all risk estimates must be updated periodically. Besides time dependence, earthquake risk estimates are sensitive to degree of fault activity, site conditions, and relationships between ground motions and expected losses. Earthquake risk assessments can provide the basis for establishing the level of earthquake hazard mitigation, insurance coverage, and contingency planning for single and multiple events. Current earthquake microzonation procedures may be enhanced by the inclusion of risk-based assessments.

● 2.4-11 Ambraseys, N. N. and Moinfar, A. A., **Iran earthquakes 1968,** *69,* Technical Research and Standard Bureau, Iran Plan and Budget Organization, Tehran, June 1977, 22.

This catalog presents instrumental data, field evidence, and related macroseismic information for 20th century earthquakes in Iran. Entries include the date, origin, and time of the seismic event. The focal location of the event estimated from instrumental results, i.e., geographical coordinates of the epicenter and focal depth in kilometers, is shown. The agency reporting the location is given in a reference column; other agencies reporting different focal estimates are also shown. In all cases, magnitude values are the average of those reported by different stations. Magnitudes determined by Soviet networks are given in brackets. The principal emphasis of this presentation is on the engineering effects of earthquakes.

● 2.4-12 Esteva, L. and Bazan, E., **Seismicity and seismic risk related to subduction zones,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 657-668.

A criterion is presented for estimation of intensity-recurrence relations at sites near subduction zones. Intensities are expressed in terms of engineering parameters (peak ground acceleration or velocity, ordinates of response spectra) for firm ground and standard flat topography. Recurrence relations for intensities are obtained from those corresponding to magnitudes of earthquakes generated at given volumes of the earth's crust (local seismicity), through use of attenuation expressions relating magnitude, intensity, and focal distance. A formulation based on the concepts of Bayesian statistics is adopted for the assessment of local seismicity at given earthquake sources by probabilistically analyzing statistical information concerning seismic activity at those sources and at others having similar geotectonic characteristics.

● 2.4-13 Moazami-Goudarzi, K. and Parhikhteh, H., **A quantitative seismotectonic study of the Iranian plateau,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 391-398.

The Iranian Plateau has been divided into 35 quadrangles. Three normalized seismic activity coefficients, the A-value, the B-value and the ratio A/B have been computed twice for each quadrangle; first using seismological data for 1900 to 1975 and second for 1965 to 1975. It was found that the A-values were of the same order of magnitude from the Bam to the Dezful region, following the Zagros ranges, as well as from Shahpour to Eshghabad, along the Alborz ranges. However, the frequency of occurrence of $M \geq 7$ earthquakes was higher in the former ranges while in the latter ranges, the most dangerous earthquakes of the plateau are more likely. The A/B values were found to be the most significant factor for earthquake engineering purposes because of its precise physical meaning. The seismotectonic aspects of the plateau have been discussed with respect to the quantitative values.

● 2.4-14 Makjanic, B., **On the maximum annual earthquake at Dubrovnik,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-04, 1978, 25-31.

The city of Dubrovnik experienced a disastrous earthquake of intensity 10 MCS (Mercalli-Cancani-Sieberg scale) in 1667. Somewhat reliable data on stronger earthquakes felt at Dubrovnik can be found in records beginning with 1430, but only since 1870 have there been complete records. The data for 1870-1969 were evaluated by means of the theory of extremes. On the basis of incomplete records for 1430-1969, rough estimates are given for return periods of intensity 7 earthquakes and higher.

2.4-15 Sieh, K. E., **Prehistoric large earthquakes produced by slip on the San Andreas fault at Pallett Creek, California,** *Journal of Geophysical Research,* **83,** *B8,* Aug. 10, 1978, 3907-3939.

Late Holocene marsh deposits composing a terrace about 55 km northeast of Los Angeles, California, contain geologic evidence of many large seismic events produced by slip on the San Andreas fault since the sixth century A.D. Several trenches were excavated in the deposits to study this evidence. The principal indicators of past events are (1) sandblows and other effects of liquefaction, (2) the termination of secondary faults at distinct levels within the

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stratigraphic section, and (3) sedimentary deposits and faulted relationships along the main fault. The effects upon the marsh deposits of six of the eight prehistoric events are comparable to those of the great (M_S = 8 1/4+) 1857 event, which is the youngest of the nine events disturbing the strata and is associated with about 4 1/2 m of right lateral slip nearby. Two large events may be smaller than this. Radiocarbon dates indicate that the events occurred in the nineteenth, eighteenth, fifteenth, thirteenth, late twelfth, tenth, ninth, seventh, and sixth centuries A.D. Recurrence intervals average 160 years but vary from one-half century to about 3 centuries. The dates may indicate a fairly systematic pattern of occurrence of large earthquakes.

● 2.4-16 Milne, W. G. and Weichert, D. H., **The sensitivity of seismic risk maps to the choice of earthquake parameters in the Georgia Strait region of British Columbia,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 323-328.

A comparison is made between the calculated values of peak horizontal ground acceleration with an annual probability exceeding 0.01 for three sites in the Strait of Georgia. The acceleration amplitudes are calculated using extreme value theory and average amplitude techniques for two acceleration functions over two periods of time. The results show a scatter within the quoted error of data used in the National Building Code of Canada.

● 2.4-17 Ucer, S. B., Ayhan, E. and Alsan, E., **A statistical approach to the determination of seismic zones for Turkey** (Turkiye'nin deprem bolgelerinin belirlenmesinde bazi istatistik yaklasimlar, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **5,** *18,* July 1977, 1-25.

In this study, seismicity, earthquake statistics, and risk are investigated for a 71-yr period for earthquakes with magnitude greater than 4.1 in order to determine seismic zones for Turkey. Since it is not possible to calculate the actual seismicity of Turkey without accurate and homogeneous data, the reliability of earthquake catalogs was checked. For this purpose, 536 earthquakes which occurred between 1918 and 1958 were examined. Significant differences were found between old and revised epicenter determinations. Therefore, except for the years before 1913, revised earthquake parameters were used.

2.4-18 Horner, R. B. and Hasegawa, H. S., **The seismotectonics of southern Saskatchewan,** *Canadian Journal of Earth Sciences,* **15,** *8,* Aug. 1978, 1341-1355.

Nine earthquakes are known or thought to have occurred in southern Saskatchewan to the present time. This small number of known events is due in part to the fact that earthquakes less than about magnitude 4 could not be instrumentally located in the region before the mid-1960s. The largest earthquake on May 15, 1909, magnitude m_b 5-1/2, was widely felt over central Canada and the north-central United States and could have been located in southern Saskatchewan, northeastern Montana, or northwestern North Dakota. Four recent minor earthquakes, one near Bengough in 1972, two near Radville, and one at Esterhazy in 1976, were all strongly felt over small areas.

There is a general spatial correlation between the observed seismicity and the more structurally disturbed areas of the Precambrian basement and overlying sedimentary sequence in the Williston Basin region. In south-central Saskatchewan, four of the instrumentally located earthquakes show a spatial correlation with a large multi-state salt-solution structure marked by a major anomaly in electrical conductivity and a steep Bouguer gravity gradient. The abundant evidence for zones of basement weakness and their control on structures in the Phanerozoic sequence suggests that reactivation of these zones in response to the contemporary stress field may also be responsible for the seismicity.

Support is given for the vertical strike-slip mechanism proposed for the 1972 Bengough earthquake. Other mechanisms considered possible for generating earthquakes in Saskatchewan are related to cavity formation in the Prairie Evaporite by either natural or industrial processes, specifically tensional faulting in the cap rock as a result of overburden pressure. Cavity collapse is not thought to be a likely mechanism for generating detectable seismic waves. Although there is a spatial correlation between some of the observed seismicity and areas of subsurface fluid injection, the absence of any direct in-situ stress measurements, the absence of knowledge of the cohesive strength of the rock in areas of fluid injection, and the absence of accurate focal depths precludes any direct correlation.

● 2.4-19 Selzer, L. A., Eguchi, R. T. and Hasselman, T. K., **Seismic risk evaluation of Southern California coastal region,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1341-1368.

A seismic risk evaluation identifying design conditions for oil lease tracts in Southern California coastal waters is presented. Earthquake design conditions are described on area maps showing expected peak ground acceleration, velocity, and displacement contours, together with response spectra for specific locations. Expected peak ground motions are calculated using a Bayesian methodology which combines geological fault information with historical seismicity data. The geological model was developed from 123 major faults and the historical model from 6364

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recorded earthquakes. Energy flux distributions are computed for both models. A linear statistical estimator is employed to revise the geological energy flux based on recorded earthquake data. Median log-linear attenuation laws are used to transform energy flux into isoseismals of peak ground motion. Partitioning of seismic energy according to frequency is evaluated by analyzing strong-motion accelerogram records. Record sets were selected to contain high-energy and long-duration features important to offshore structures. Normalized response spectra are derived from an analysis of accelerogram data sets, and spectral ordinates are combined with ground motion values from the isoseismal maps to obtain response spectra for specific offshore locations. A probabilistic model is applied which expresses design spectra and isoseismal maps in terms of the probability of exceeding specified motions or as a function of the return period for the specified motions.

● 2.4-20 Anderson, J. G., **On the attenuation of modified Mercalli intensity with distance in the United States,** *Bulletin of the Seismological Society of America,* 68, *4,* Aug. 1978, 1147–1179.

A large number of modified Mercalli intensity isoseismal maps for earthquakes which have occurred in the United States have been analyzed to find the distribution of distances (R) between the epicenter and the isoseismal contours. The data include most of the maps in the series *United States Earthquakes,* and a smaller number of maps from other sources. Where the data permit, best fitting parameters have been found in a Gaussian distribution function to fit the observed distributions of $\log_{10}R$ for each combination of epicentral intensity and the intensity bounded by the contour. The data do not contradict this assumed Gaussian shape. The standard deviation of $\log_{10}R$ is at best 0.2 for well-determined distributions; it is typically 0.3, implying that over an order of magnitude range of distances is present in the data.

● 2.4-21 Hadley, D. and Kanamori, H., **Recent seismicity in the San Fernando region and tectonics in the west-central Transverse Ranges, California,** *Bulletin of the Seismological Society of America,* 68, *5,* Oct. 1978, 1449–1457.

Since the San Fernando earthquake of Feb. 1971, the density of the southern California seismic array has increased by an order of magnitude. The enhanced coverage provides an ideal setting for the study of the long-term seismicity of the San Fernando aftershock zone and adjacent regions. Most of the recent activity within the San Fernando zone has been thrust faulting at locations south of the main shock and at depths shallower than the main shock. One event located slightly deeper than the main event, and several kilometers north, suggests shear along a flat plane. Transport of the upper block is south. This event is very similar to another deep (M_L = 4.5) earthquake 30 km west of San Fernando. If these events are typical of midcrustal deformation, the west-central Transverse Ranges may be a form of decollement. A rapid increase in seismicity ($M_L \geq 3.0$) in the region south of San Fernando suggests an increase in regional strain that either was contemporaneous with the San Fernando earthquake or immediately followed it.

● 2.4-22 Marks, S. M. and Lindh, A. G., **Regional seismicity of the Sierran foothills in the vicinity of Oroville, California,** *Bulletin of the Seismological Society of America,* 68, *4,* Aug. 1978, 1103–1115.

The USGS (U.S. Geological Survey) operated 16 short-period seismic stations near Oroville, California, in conjunction with the authors' aftershock study of the Oroville earthquake of Aug. 1, 1975 (M_L = 5.7). Between June 1975 and Aug. 1976, 35 earthquakes were recorded outside the aftershock zone with *S-P* times at Oroville less than 9 sec and magnitudes between 0.5 and 2.5. Those earthquakes between 3845′ and 4015′N and 12030′ and 12215′W have been located using the USGS Oroville network, supplemented with data from other regional stations. Maps are shown relating this regional seismicity to the Oroville aftershock zone, the M = 5.7 Chico event of 1940, and the historical seismicity. Of particular interest are two small but very well located events at a depth of 40 km down-dip from the Oroville aftershock zone.

2.4-23 Watanabe, K., Hirano, N. and Kishimoto, Y., **Seismicity in the Hokuriku district** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* 31, *1,* Mar. 1978, 35–47.

Observation of microearthquakes was conducted from May 1976 to July 1977 at the Hokuriku Microearthquake Observatory, Disaster Prevention Research Inst., Kyoto Univ. In this article, seismicity in the Hokuriku area was investigated by use of a telemeter. Historical data for large earthquakes were also studied. Microseismicity was found to be high from the Fukui plain to the northeastern side of Lake Biwa, and from the west coast of Lake Biwa to the Wakasa Bay. In contrast, microseismicity is relatively low in other areas of Lake Biwa, offshore from the Sea of Japan, and in the northern part of the Gifu and Ishikawa prefectures. It is suggested that microseismicity in this area is related to large tectonic structures, such as the Fuki Neodani, and Yanagase faults. In general, these active faults form boundaries between seismic and aseismic areas. It was also found that areas of active microearthquakes nearly coincide with those of past disastrous earthquakes, and that for the latter there seem to be some regularities of occurrence spatially and temporally.

● 2.4-24 Sinvhal, H. *et al.,* **Neo-tectonics and time-space seismicity of the Andaman-Nicobar region,** *Bulletin of the*

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Seismological Society of America, 68, 2, Apr. 1978, 399–409.

The seismicity of the Andaman-Nicobar region has been analyzed in space and time. The space distribution of epicenters brings out a gap in seismicity which is situated at the northern end of Andaman Island. Such seismically quiet zones at tectonically active plate boundaries can constitute a seismic hazard in the near future. However, for this gap it could not be established that such is the case. The earthquake focal mechanism studies show that the area on the northeastern side of the arc is undergoing normal faulting along two zones enclosing a graben feature between them, which is also the area where the Irrawaddi River dumps its sedimentary load. The eastern margin of this interpreted graben is associated with a submarine channel which appears to have a seismotectonic control.

The great 1941 earthquake in this area is inferred to have a nearly north-south fault extending for about 800 km. The northern and southern edges of this fault displayed continued aftershock activity for several years. There was a general decrease in seismic activity in the entire area for three years following the great earthquake.

2.4-25 Kono, Y., **Computer program for observation of time- and space-variations of seismicity** (in Japanese), *Zisin, Journal of the Seismological Society of Japan*, **31**, *1*, Mar. 1978, 49–62.

A computer program which displays the time and space variation of seismicity in a chosen area is presented. A refresh-type computer graphic display unit is employed. The program does the following: (1) draws a map of an area using a map-projection method; (2) displays earthquakes on the map chronologically; (3) plots a symbol at the earthquake's epicenter, which characterizes the magnitude and focal depth; (4) erases the symbol from the display after a specified time; and (5) displays a time and date. During programming, the display can be temporarily "frozen," and the ratio of real and simulation time, the duration of the display, and the time and the date of an earthquake can be altered.

Results of display experiments illustrated in this paper include (1) world seismicity, particularly before and after the Kanto earthquake (Sept. 2, 1923; M=7.9); (2) the seismicity of the Japanese islands, particularly before and after the Niigata earthquake (June 16, 1964; M=7.4); and (3) seismicity in the northeastern Japanese islands, particularly before and after the 1968 Tokachi-oki earthquake (May 16, 1968; M=7.9). The experiments suggest that studies of the temporal variations in the pattern of seismicity are important because they (1) show characteristic features of earthquake occurrence; (2) increase understanding of present and past seismicity; (3) allow comparison between laboratory experiments on the failure of materials and real seismicity; (4) provide correlations between seismicity and other natural phenomena, such as volcanism and crustal deformation; and (5) detect hidden regularities in the seismicity patterns.

● **2.4-26** Allen, C. R., **Study of seismicity and earthquake engineering in the Long Beach-San Diego coastal and offshore region, California**, Seismological Lab., California Inst. of Technology, Pasadena, California, Apr. 15, 1978, 17.

The purpose of this study was to determine more accurately the seismicity and the seismic hazard of the Long Beach-San Diego coastal and offshore area, and to better understand the engineering response to earthquakes of soils and structures of particular interest to the United States Navy.

● **2.4-27** **New England seismotectonic study activities during fiscal year 1977**, Weston Observatory, Boston College, Weston, Massachusetts, May 1978, 138.

The New England Seismotectonic Study is a program of investigations designed to better understand the manifestations and causes of seismicity in New England and adjacent areas in order to assess the seismic hazard and its variation within the region. The aims of the initial effort are to: (1) compile and analyze available pertinent information on seismicity, geology and geophysics in the region; (2) acquire new information by investigating previously well-defined problems; and (3) develop and organize a comprehensive program that, in five years, will provide an overall assessment of the seismic hazard of the region. The program will integrate seismological, geophysical, geological and remote-sensing studies to complement the program of the Northeastern U.S. Seismic Network.

Results thus far document the importance of faulting in the region and demonstrate the effectiveness of remote-sensing, magnetic-lineament and gravity-lineament analyses to reveal faults in the region. The present data also indicate that the more information available on earthquake location and faults in an area the closer the spatial relation of earthquakes with faults.

● **2.4-28** Rowshandel, B., Nemat-Nasser, S. and Adeli, H., **A tentative study of seismic risk in Iran**, *Technical Report 78-3-9*, Earthquake Research and Engineering Lab., Northwestern Univ., Evanston, Illinois, Mar. 1978, 130.

Using the Poisson model, tentative probabilistic estimates of future earthquakes in Iran are obtained on the basis of earthquakes recorded during this century. The results are presented in terms of the cumulative distribution function for the peak ground acceleration for several major cities and in the form of iso-acceleration maps at different levels of risk and for different time periods. Based

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on the cumulative distribution of peak ground acceleration, graphs of return periods are constructed for the major cities. The graphs can be used to obtain the design value of the peak ground acceleration when the economic life and the level of risk are prescribed for a structure.

● 2.4-29 Kovacs, W. D. and Murphy, W. J., **The seismicity of Indiana and its relationship to civil engineering structures—phase B,** *JHRP-77-21,* Joint Highway Research Project, School of Civil Engineering, Purdue Univ., West Lafayette, Indiana, Dec. 21, 1977, 124.

Included in this interim report on the seismicity of Indiana are the following topics: Literature Survey, Seismic History, Regional Geology—Seismo-Tectonics, Probability and Statistics, and Design Earthquakes. Other topics to be covered at a later date include: Site Response, Response Spectra—Time History, Microzonation Studies, Building Code Review, Specific Conditions—Highways and Bridges, Specific Conditions—Buildings, and a Final Report.

● 2.4-30 Lomnitz, C., **Seismological trip to the People's Republic of China—field notes** (Mision sismologica a la Republica Popular China—notas de campo, in Spanish), *Comunicaciones Tecnicas No. 158,* Inst. de Investigaciones en Matematicas Aplicadas y en Sistemas, Univ. Nacional Autonoma de Mexico, Mexico City, 1977, 101.

● 2.4-31 Golenetsky, S. I. and Misharina, L. A., **Seismicity and earthquake focal mechanisms in the Baikal rift zone,** *Tectonophysics,* **45,** *1,* Jan. 17, 1978, 71–85. (Paper presented at Symposium on the Rift Zones of the Earth, Sept. 1975, Irkutsk, U.S.S.R.)

The seismicity of the Baikal rift zone is considered on the basis of instrumental and field observations. The spatial pattern of epicenters, the frequency of earthquakes, and the relationship between seismicity and the elements of fault tectonics are analyzed. The regional and local stress states in the crust of the Pribaikalye region, obtained by studying earthquake focal mechanisms for various energies, are summarized.

● 2.4-32 Su, S. S., **Earthquake risk analysis for Metro Manila,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 33–43. (For a full bibliographic citation see Abstract No. 1.2-3.)

Gumbel's extreme value theory is applied to the estimation of probabilities of occurrence and return periods of large earthquake intensities in metropolitan Manila. The probability model of Epstein and Lomnitz is used. Methods of calculation follow those of Epstein and Lomnitz and those of Shakal and Willis. Two sets of data are analyzed, namely, from 1861 to 1940 and from 1952 to 1976. Results of regression analysis show very good agreement between the two sets, even though their time intervals differ considerably. This work for metropolitan Manila is a pilot project for a much larger undertaking, that is, the seismic zoning of the entire Philippines.

● 2.4-33 Dombroski, Jr., D. R., **Earthquakes in New Jersey,** revised, Dept. of Environmental Protection, New Jersey Bureau of Geology and Topography, Trenton, 1977, 30. (NTIS Accession No. PB 283 771)

New Jersey is not located in a seismic area and has experienced only four earthquakes large enough to have caused extensive damage and destruction. Two were in the St. Lawrence River Valley; all four were felt in New Jersey, but none caused major damage there. In this report, all the major or minor earthquakes large enough to be felt in New Jersey, and a few too weak to be felt but detected by seismographs, are tabulated. The report also includes a brief discussion of seismology, a listing of the seismograph stations in and near New Jersey, and an account of minor seismic activity related to the Triassic Border fault and other areas in the state.

● 2.4-34 Makino, M. and Matsumura, K., **A correlation between the recurrence intervals of active faults and the extreme value distributions of earthquake ground motions,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 3, Nov. 1978, 17–24.

Great earthquakes have recurred in several subduction zones around Japan. The recurrence intervals of fault movements have been estimated by geological and geomorphological studies for a number of active faults in central Honshu. Based on Gutenberg and Richter's magnitude-frequency law, it may be assumed that the recurrence interval of great earthquakes is inversely proportional to the occurrence rate of the earthquakes in the same region. The occurrence rate of earthquakes and the b-value of Gutenberg and Richter's law are important measures for the seismic risk analysis of a particular site. Using the Poisson process for the occurrence of major earthquakes, the probabilistic procedure after Cornell yields a satisfactory estimate of the extreme value statistics when an appropriate attenuation relation is employed. It may be possible, therefore, to calculate the recurrence intervals of great earthquakes by seismic risk analysis in a probabilistic sense.

A seismic risk map partly dependent on this probabilistic procedure is derived and compared with Kanai's map, which is obtained from historical earthquake documents. Since the same attenuation relation is employed, the maps are nearly identical except for several regions most affected by recent great earthquakes. It seems evident that there is a correlation between the recurrence interval of great earthquakes and the seismicity of recent times in the active region. The results from active fault studies will be taken into account in developing an improved seismic risk map.

● 2.4-35 Srivastava, H. N. and Chaudhury, H. M., **Possibility of a large earthquake in "seismic gap' of Himachal Pradesh, India,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 45, Nov. 1978, 353-359.

The epicenters of more than 1000 microearthquakes have been recorded during 1965-1974 by a close network of seismological observatories that were established for a river valley project. These data have been used to demarcate a well-defined seismicity gap in Himachal Pradesh. By taking into account the regional plate tectonics and the past history of damaging earthquakes, namely, Kangra (1905) and Kinnaur (1975) with epicenters located near the western and eastern margins of the seismic gap, it has been estimated that earthquakes of magnitude 7.5 could occur in this zone.

● 2.4-36 **Earthquake Study: Venezuela,** Reinsurance Offices Assn., London, 1978, 41.

The purpose of this report is to assess the risk of earthquake losses in Venezuela. The regional setting of the country is described and relevant seismological data are considered, including the record of earthquake damage from historical accounts of the past 400 years and the distribution of epicenters from instrumental measurements beginning in the early 20th century. The historical record forms the basis for establishing the frequency of occurrence of damaging earthquakes, while the instrumental data provide important seismological details about magnitudes, epicentral distances, focal depths, and ground movements. The instrumental data are equally important for predicting the performance of larger structures of modern design. Consideration of the influence of site geology is followed by a study of secondary effects such as tsunamis, liquefaction, landslides, and fires following earthquakes. The report concludes with a study of regulations and design and building practices.

● 2.4-37 Aggarwal, Y., **Study of earthquake hazards in New York and adjacent states–phase IV,** *NYSERDA 75/37,* Lamont-Doherty Geological Observatory, Columbia Univ., Palisades, New York, Sept. 1977, 39. (NTIS Accession No. PB 276 562)

Over the past six years, the Lamont-Doherty Geological Observatory has installed a network of 37 short-period seismic stations in New York state and adjacent parts of New Jersey and Vermont. The purpose of the network is to acquire data crucial to the study of the earthquake hazard in this area. The analyses of the data have resulted in a number of important findings, including the identification for the first time of several active faults. Earthquakes in northern New York and adjacent Quebec occur preferentially along NNW trending fault planes. In the southern New York-northern New Jersey area earthquakes occur along pre-existing faults trending N to NE. High-angle reverse faulting, in contrast to the normal faulting that occurred during the Triassic period, appears to be the predominant type of contemporary fault movement in the greater New York City area.

● 2.4-38 Scawthorn, C., Yamada, Y. and Iemura, H., **Seismic risk analysis of urban regions,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 176, Nov. 1978, 1399-1406.

The seismic risk of an urban region is defined as the probability of damage, which is a function of seismic hazard and vulnerability. Seismic hazard is presented in the form of probabilistic response spectra for three types of soils, using published attenuation regressions and extreme-value–type seismicity relations. Vulnerability, in terms of a damage ratio, is correlated with spectral attenuations for urban Japan. Using this correlation and the computed seismic hazard, probabilities for the damage ratio are readily obtained. The method is applied to the Osaka region and probabilistic response spectra are obtained which agree with available results. Seismic risk is then expressed for Osaka in terms of the probabilities of damage ratio for three types of soils.

● 2.4-39 Gurpinar, A. and Gulkan, P., **Preliminary seismic risk assessment for northwestern Turkey,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. III, 790-808. (For a full bibliographic citation, see Abstract No. 1.2-7.)

A general procedure is outlined for a preliminary regional seismic risk assessment for the siting of nuclear power plants. A detailed illustrative study of northwestern Turkey exemplifies the procedure. The article also includes a tentative comparison of the seismicity of the region in Turkey with the Friuli region of Italy where a major earthquake occurred in May 1976.

● 2.4-40 Benvegnu, F. *et al.*, **Seismotectonic investigations in northeastern Italy,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 103-131. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Northeastern Italy has been the site of geomorphologic, tectonic, and seismicity investigations. The elaboration and the correlation of the collected data have evidenced a well-defined seismotectonic area characterized by its historic seismicity and type of tectonics. The tectonic

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structures connected with historic earthquakes of intensities greater than the Friuli earthquakes have been identified within the area. Outside the area, the zones with more elevated seismic wave propagation and attenuation are delineated.

● **2.4-41** Abbott, P. L. and Victoria, J. K., eds., **Geologic hazards in San Diego: earthquakes, landslides, floods,** San Diego Society of Natural History, San Diego, California, 1977, 96.

This book is the result of a public lecture series on local geologic hazards sponsored by the San Diego Natural History Museum in the autumn of 1976. Included are articles on earthquake prediction and landslides in the San Diego area.

● **2.4-42** Coffman, J. L. and Stover, C. W., eds., **United States earthquakes, 1976,** U.S. National Oceanic and Atmospheric Admin. and U.S. Geological Survey, Boulder, Colorado, 1978, 94.

This report, one of an annual series, describes all earthquakes that occurred in the United States and nearby territories in 1976. The purpose of these reports is to provide a continuous history of U.S. earthquakes in order to study seismic risk, evaluate nuclear power plant sites, design earthquake-resistant structures, and answer inquiries from the scientific community and the general public. This publication is composed of three chapters: "Earthquake Descriptions," which includes a chronological list of earthquakes by state in 1976 and a summary of macroseismic data reported for each event; "Miscellaneous Activities," which contains information on crustal movement studies, tsunamis, principal earthquakes of the world, and fluctuations in well-water levels; and "Strong-motion Seismograph Data." The intensity and macroseismic data in the chapter on earthquake descriptions were compiled from questionnaire canvasses, newspaper articles, and reports prepared by other government organizations, state and local institutions, and individuals. Each description includes date, origin time, hypocenter and hypocenter source of the earthquake, magnitude, maximum intensity (modified Mercalli), and the macroseismic effects reported in the area.

● **2.4-43** Erdik, M. and Ozselcuk, A., **Regional rearrangement of earthquake catalogues of Turkey** (Turkiye deprem kataloglarinin bolgesel duzenlemeler, in Turkish), *METU/EERI 78/6,* Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, Turkey, Dec. 1978, 95.

A regional rearrangement of two earthquake catalogs of Turkey is presented. These catalogs are *An Earthquake Catalogue for Turkey for the Interval 1913-1970* by Alsan, Tezucan, and Bath, and the U.S. National Oceanic and Atmospheric Admin.'s Earthquake Data File between 34° - 43° and 24° - 46° E coordinates. The earthquakes are listed in order of decreasing magnitude for each of the 0.5° x 0.5° coordinate areas. This type rearrangement is useful for macrozonation and seismic risk analysis in earthquake engineering.

● **2.4-44** Burton, P. W., **Assessment of seismic hazard in the UK,** *Instrumentation for Ground Vibration and Earthquakes,* Proceedings of the Conference of the Society for Earthquake and Civil Engineering Dynamics, Institution of Civil Engineers, London, Paper 3, 1978, 35-48.

Historical files of earthquakes are the major data source for seismic hazard assessment in the United Kingdom. Extreme value statistics may be applied to these data sets and recurrence intervals obtained for different energy levels. On the basis of simplified recurrence statistics, comparable strong-motion data may be selected as representative of a regional seismic hazard.

● **2.4-45** Kasahara, J., Nagumo, S. and Koresawa, S., **Seismic activity in Sagami Bay and off the Boso Peninsula observed by ocean bottom seismographs in 1971,** *Journal of Physics of the Earth,* **26,** *2,* 1978, 199-210.

In 1971, for a period of approximately ten days, OBS observations were carried out in Sagami Bay, south of Tokyo, where the 1923 Kanto earthquake (M=7.9) occurred, and where seismic activity has been very low since 1926. Although the OBS on the Sagami Trough detected one near earthquake of magnitude 0.1, it is concluded that the shallow seismic activity in Sagami Bay around the terminus of the Sagami Trough was very weak in late 1971. It is also concluded that the 1923 earthquake fault postulated to be in Sagami Bay is still quiet at present in spite of the recent unusual crustal deformation in the adjacent region, the Boso Peninsula. Use of an OBS, along with several land-based stations, expanded the detection capability to the area south of the Boso Peninsula. The hypocenter distribution revealed a linear alignment extending to the southeast from the tip of the Boso Peninsula at a mean depth of about 60 km. The vertical distribution of hypocenters along the linear alignment resembles the bathymetric feature of the sea floor. There was a depth discontinuity of hypocenters at the foot of the inner wall of the Sagami Trough at 34.8°N.

2.4-46 Ahorner, L. and Rosenhauer, W., **Seismic risk evaluation for the upper Rhine graben and its vicinity,** *Journal of Geophysics,* 44, 5, 1978, 481-497.

A probabilistic large-scale seismicity model for the upper Rhine graben and adjoining regions has been developed using all available seismological and geological information. With this model, the probability distribution of macroseismic intensities (MSK-scale) is calculated for 208 sites, covering the region under investigation with a grid width of 25 km. Four maps with intensity isolines are

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presented according to exceedance probabilities of 63%, 10%, 1%, and 0.1% for a period of 50 years (corresponding to annual occurrence rates of $2 \cdot 10^{-2}$, $2 \cdot 10^{-3}$, $2 \cdot 10^{-4}$, and $2 \cdot 10^{-5}$). The intensities given reflect the regional seismicity level with respect to quantitative risk values, which might be modified by local characteristics (soil conditions, nearby seismoactive fault lines, etc.) of a site. The risk for an average site in the upper Rhine graben is characterized by an annual occurrence rate of about 10^{-4} for intensity VIII. On a statistical basis, the possibility of exceeding intensity IX cannot be excluded, but is of only very low probability.

2.4-47 Lukk, A. A., **Space-time sequence of weak earthquakes in Garm region,** *Physics of the Solid Earth,* **14**, 2, Sept. 1978, 100–108.

The space-time sequences "chains" of weak earthquakes (K=6-10) of the Garm region are analyzed. It is shown that the earthquake chains, connected in space and time and consisting of five or more events, occur within the confines of a limited number of relatively narrow linear zones, forming a simple grid in the region of their intersection. In individual cases, this zone coincides with the fracturing of the crust of the earth. In the general case, it is surmised that the earthquake chains emerge in the zones of development of "rapid" deformations of the crustal material. This postulate enables one to consider the earthquake chains as a characteristic of the deformation process of the region. The possibility is discussed of using the temporal variations in the density of the earthquake chains for predicting strong earthquakes.

2.4-48 Smith, W. D., **Spatial distribution of felt intensities for New Zealand earthquakes,** *New Zealand Journal of Geology and Geophysics,* **21**, *3*, 1978, 293–311.

The isoseismals of shallow earthquakes in New Zealand exhibit three classes of intensity decay with distance, each characteristic of a particular geographical region. The calculation of the likely intensity at any place from an earthquake whose location and magnitude are specified uses an empirical formula appropriate to the region in which the shock is located, and also the ellipticity of the isoseismals, a parameter which varies throughout the country. The formula for deep earthquakes incorporates the offset of the isoseismals from the epicenter and their ellipticity, both modeled as functions of focal depth. The calculation of intensity has a standard error of about one unit, and is a useful tool for estimation of the earthquake risk.

2.4-49 Smith, W. D., **Earthquake risk in New Zealand: statistical estimates,** *New Zealand Journal of Geology and Geophysics,* **21**, *3*, 1978, 313–327.

From the historical record of New Zealand earthquakes, the mean return periods for modified Mercalli intensities VI, VII, VIII, and IX throughout the country are calculated. The results are presented in the form of contour maps and a tabulated list for 19 cities and towns. The work documents events since 1840. The results may be used for future planning on the assumption that the historical record represents an average level of activity.

2.4-50 Eva, C. *et al.*, **Seismicity and its relation with surface structures in the north-western Apennines,** *Bollettino di Geofisica,* **XX**, *79*, Sept. 1978, 263–277.

A seismotectonic map of the northwestern Apennines, for the period ranging between 1800 and 1977, is presented. The historical and recent activity have been revised and relocated. The broad area appears to be very active; complex faulting and epicenter distribution suggest that tectonic stress in the zone may be relieved by a continuous series of small-to-moderate earthquakes. Seismicity maps for different periods suggest that most of the activity occurs in two main areas, the Tyrrhenian slope and along the Padanian margin of the belt. From a geological point of view, the western area of the northern Apenninic domain is characterized by recent distensive tectonics, with a horst and graben structure, while in the external Padanian margin of the belt compression, which was presumably active up to the Quaternary period, buried folds under the flat sedimentary blanket can be deduced. Epicenter lineups of microearthquakes and small earthquakes correlate well with mapped faults or geological lineaments. By using statistical methods, probabilities and recurrence times for different magnitudes are evaluated.

● 2.4-51 Benhart, B. and Jaffery, S. Z. S., **Earthquakes: their nature and effects on Guam,** *Vulnerability Study Series Report No. III,* Disaster Preparedness Planning Program, Guam Bureau of Planning, Agana, June 1978, 87.

The contents of the report are the following: Introduction; Types of Movement During Earthquakes; Scales of Measurement of Earthquakes; Physical Factors Affecting Guam; Fault Zones on Guam; Earthquakes on Guam; Earthquake Related Hazards; Adaptations to Earthquakes on Guam: Recommendations.

● 2.4-52 **Earthquake study: Puerto Rico,** Reinsurance Offices Assn., London, Mar. 1976, 28.

This report assesses the risk of damaging earthquakes in Puerto Rico. The regional setting of the island is described, and relevant seismological data, consisting of historical records of earthquake damage and the distribution of epicenters from instrumental measurements beginning in the early years of the 20th century, are presented. Also considered are the influence of site geology; seismic

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building practices, regulations, and design; and such secondary effects as tsunamis, fires, liquefaction, and large-scale ground movement.

● **2.4-53** **Earthquake study: Jamaica,** Reinsurance Offices Assn., London, Mar. 1976, 36.

This report assesses the risk of damaging earthquakes in Jamaica. The seismicity of the Jamaican region, particularly the importance of the Cayman, or Bartlett trough, is discussed. Also discussed are the historical data for the region, the effects of geology on seismic risk, and building regulations and practices. Special attention is paid to the effects of geology on risk in Kingston.

● **2.4-54** **Earthquake study: Israel,** Reinsurance Offices Assn., London, Mar. 1976, 36.

This report describes the risk of damaging earthquakes in Israel. The regional setting and relevant seismological data are presented. These data consist of the record of earthquakes from historical accounts during the last 2000 years and the distribution of earthquake epicenters from instrumental measurements beginning in the early 20th century. The various attempts to produce regional maps of seismic activity are described. Following this, the effects of site geology are studied. The penultimate part investigates building methods and designs and the report concludes with a study of seismic sea-waves in this low-lying coastal region.

● **2.4-55** **Earthquake study: Trinidad & Tobago,** Reinsurance Offices Assn., London, Mar. 1976, 31.

This report assesses the risk of damaging earthquakes in Trinidad and Tobago. The general seismicity of the Trinidad region, particularly the importance of the Caribbean Plate is described. Discussed are the historical data for the region, the effects of geology on seismic risk, with special attention to the problem of Port of Spain/Arima, and secondary effects. The report concludes with consideration of building regulations and design.

● **2.4-56** Encarnacion, R. P., **Seismicity of the Philippines and the expectations of maximum earthquake motions,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 127–141.

This paper deals with the seismic activity in the Philippines for the period 1901 to 1974. With the aid of Gutenberg-Richter's statistical relation and the modification of this relation by Welkner, an expected b-value and an expected a-value, regarded as the index of the mean annual seismic activity, were computed for the area. This report estimates the expected maximum earthquake motions, that is, the particle velocity at the base rock and the acceleration on the ground at their extreme values for certain return periods. For the maximum velocity calculations, Kanai's attenuation model was used; and, for the maximum acceleration, the average of McGuire and Oliveira's attenuation models was considered. Computer programs were used in the analysis. Nineteen sites were evaluated; the results compared favorably with known Philippine seismicity.

● **2.4-57** **Earthquake study: Australia,** Reinsurance Offices Assn., London, Dec. 1977, 61.

This report examines the seismicity of Australia. Although Australia has been long regarded as virtually inactive from the earthquake point of view, there are areas where damage has occurred. The paper points out that, in most metropolitan areas, seismicity is relatively low, but the possibility of damage cannot be entirely discounted.

● **2.4-58** **Earthquake study: Mexico,** Reinsurance Offices Assn., London, Nov. 1977, 41.

This report assesses the risk of damaging earthquakes in Mexico. Relevant seismological data are presented, including the record of earthquake damage from historical accounts over the last 500 years and the distribution of epicenters from instrumental measurements beginning in the early years of this century. The historical record forms the basis for establishing the frequency of damaging earthquakes, while the instrumental data provide seismological details about magnitudes, epicentral distances, focal depths, and ground movements. The influence of site geology is examined, followed by a study of secondary effects such as tsunamis, liquefaction, landslides, and fire following earthquakes. Building regulations, design, and construction practices are also reviewed.

● **2.4-59** **Earthquake study: Ecuador,** Reinsurance Offices Assn., London, Jan. 1978, 37.

This report discusses earthquake risk in Ecuador. The evidence suggests that Ecuador can be divided into low-, intermediate-, and high-risk regions coinciding broadly with the areas to the east of the Andes, the Andes themselves, and the areas to the west of the Andes, respectively. The general seismicity of the Ecuador region is discussed with particular attention given to the junction of the Nazca and South American plates. The historical record is presented to supplement the short-term instrumental record. Building regulations, practices, and design are examined with the effects of geological conditions and design features on the earthquake risk taken into consideration. The paper includes maps, diagrams, tables and graphs, and a list of sources. An apparent return period of 9 years for magnitude 7.5, 21 years for magnitude 8.0, and 43 years for magnitude 8.5 somewhere in the Ecuador region is found.

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

Based on the historical and instrumental records and distances involved, insurance writers may consider that Quito and Guayaquil would not both be seriously affected by a single large event.

● 2.4-60 Numanoglu, A. B., **Seismic risk analysis for western Anatolia** (Bati anadolunun deprem riski analizi, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **6**, *21*, Apr. 1978, 44-52.

The extreme value method is applied to a statistical model of the seismic risk for western Anatolia.

● 2.4-61 Hattori, S., **Seismic risk maps in the world (maximum acceleration and maximum particle velocity) (I)—China and its vicinity,** *Bulletin of the International Institute of Seismology and Earthquake Engineering*, **16**, 1978, 119-150.

Seismic risk maps for China and its vicinity were constructed by using seismic data for the period 1581-1976, attenuation models, and Gumbel's third asymptotic distribution. The maps consist of the following two types: (1) maximum particle velocity (kine) on base rock and (2) maximum acceleration (gal) on the ground. The return periods of these maps are 50, 100, 200, and 300 years.

● 2.4-62 Hattori, S., **Temporal variations of seismicity and seismic risk in and around Japan,** *Bulletin of the International Institute of Seismology and Earthquake Engineering*, **16**, 1978, 105-118.

Temporal variations of the seismicity in Japan were studied by using cumulative energy curves. The values of S(T) were estimated from the energy curves. The S(T) values imply that, when the temporal variations of the seismicity are assumed to be repeated by the period Tr, S(T) x Tr years will have passed from the previous great earthquake. The regional distribution of the S(T) values in the vicinity of Japan was obtained. The author studied the expected maximum earthquake motion based only on the spatial characteristics of the seismicity (S(S)) and on the ground characteristics (M(S)), and the regional distributions in and around Japan are shown for both. It is proposed that a more reasonable seismic risk map should be shown by combining S(S), M(S) and the temporal variations of the seismicity (S(T)).

● 2.4-63 Panza, G. F., ed., **Bibliography of statistical aspects of seismicity,** *Report SE-13*, World Data Center A for Solid Earth Geophysics, Boulder, Colorado, Aug. 1978, 74.

● 2.4-64 Fuis, G. S., Friedman, M. E. and Hileman, J. A., **Preliminary catalog of earthquakes in southern California, July 1974-September 1976,** *USGS Open-File Report 77-181*, California Inst. of Technology, Pasadena, California, 1976, 107.

● 2.4-65 Schnapp, M. and Fuis, G., **Preliminary catalog of earthquakes in the northern Imperial Valley, October 1, 1976-December 31, 1976,** *Open-File Report 77-431*, U.S. Geological Survey, n.p., 1977, 21.

● 2.4-66 Schnapp, M. and Fuis, G., **Preliminary catalog of earthquakes in the northern Imperial Valley, January 1, 1977-March 31, 1977,** *Open-File Report 78-74*, U.S. Geologic Survey, n.p., 1978, 15.

2.5 Studies of Specific Earthquakes

2.5-1 Kanamori, H. and Stewart, G. S., **Seismological aspects of the Guatemala earthquake of February 4, 1976,** *Journal of Geophysical Research*, **83**, *B7*, Paper 8B0225, July 10, 1978, 3427-3434.

Detailed analyses of teleseismic surface waves and body waves from the Guatemala earthquake of Feb. 4, 1976, show the following: (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 2.6×10^{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/s was used, and the fault curvature was 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 10 independent events, each having a seismic moment of $1.3\text{-}5.3 \times 10^{26}$ dyne cm and a fault length of about 10 km. The spatial separation of these events varies from 14 to 40 km. This multiple-shock sequence suggests that the rupture propagation is jagged and partially incoherent with an average velocity of 2 km/s. (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 an 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.

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

● 2.5-2 Berberian, M. and Papastamatiou, D., **Khurgu (North Bandar Abbas, Iran) earthquake of March 21, 1977: a preliminary field report and a seismotectonic discussion,** *Bulletin of the Seismological Society of America,* 68, 2, Apr. 1978, 411–428.

The Khurgu earthquake of magnitude M_S = 7.0 occurred on Mar. 21, 1977, in the mountains about 40 km north of Bandar Abbas in southern Iran. It killed 152 people, injured 556, and caused destruction over an area of 550 km^2. The shock damaged 1500 houses beyond repair and killed 1.3% of the livestock in the area. The maximum intensity of the main shock just exceeded VIII (MM). The earthquake was not associated with any fresh surface faulting nor with reactivation of existing faults or movements of salt domes at the surface. Small and large landslides and rockfalls occurred on steep slopes. A huge rock fall destroyed a village in the eastern part of the epicentral region. Water changed in springs, and in one well water became more salty. Very intense vibration was noticed at the top of narrow and elongated high Quaternary alluvial terraces where displaced and upturned stones were found. A foreshock, which occurred approximately 10 sec before the main destructive shock, gave an early warning and enough time for many people to run out of doors, thus saving their lives. This seems the reason for the relatively low number of casualties. The earthquake hit the epicentral areas of two recent events: the 1975 (m_b = 5.8 - 6.1) and the 1977 (M_S = 5.2) earthquakes. However, past damage did not affect the new macroseismic pattern. The only pronounced distortion on the main shock macroseismic pattern was produced by an aftershock 12 hr later. The Khurgu earthquake is another "subsedimentary Zagros-type earthquake" case in the Zagros active folded belt, indicating that the adjustment of the metamorphosed Precambrian basement at depth caused no tectonic deformation (surface faulting) at the top of the sedimentary cover. The earthquake is of major engineering significance since it provided evidence of the ground-motion characteristics of a rare large event in the Zagros.

● 2.5-3 Herrmann, R. B., **A seismological study of two Attica, New York earthquakes,** *Bulletin of the Seismological Society of America,* 68, 3, June 1978, 641–651.

The Attica, New York, earthquakes of Jan. 1, 1966, and June 12, 1967, are examined in detail and their focal mechanisms, depths, and seismic moments are given. Both events have similar source parameters, with one nodal plane striking about 120° and dipping 60°S and the other nodal plane striking about 20° and dipping 70°E. The fault motion on the NNE nodal plane has one component of right lateral strike slip and one of reverse faulting. Though this nodal plane parallels the Clarendon-Linden structure, the possibility of associating the other nodal plane with a diffuse east-west seismicity trend cannot be excluded. The shallow focal depth of 2 to 3 km for these two events can be used as an explanation of the relatively high epicentral intensity (VIII) of the Attica event of 1929.

● 2.5-4 Rogers, G. C. and Hasegawa, H. S., **A second look at the British Columbia earthquake of June 23, 1946,** *Bulletin of the Seismological Society of America,* 68, 3, June 1978, 653–676.

Available near- and far-field data have been used to reassess and reevaluate the focal parameters of the June 23, 1946, British Columbia earthquake. The preferred epicenter (49.76°N, 125.34°W) is located on Vancouver Island, inland from the population centers along the east coast. This location is consistent with observed intensities, water disturbances, and calculated ground deformation. The hypocentral depth is near 30 km, making surface rupture a distinct possibility. A revised fault-plane solution indicating strike-slip faulting (probably right lateral on a northwest striking plane), though not a unique interpretation, is the most consistent with observed intensities, water disturbances, and calculated ground deformation. A new surface-wave magnitude calculation of 7.2 ± 0.1 agrees with the previously published value of 7.3. Calculated source parameters are as follows: seismic energy release of 5.6 X 10^{22} ergs; seismic moment of 2.5 X 10^{27} dyne-cm for the preferred (strike-slip) solution; and an apparent stress of 10 bars for the preferred solution. The small number and relatively small size of aftershocks may be indicative of a high stress drop, but a reliable evaluation of stress drop is not possible because of uncertainties in estimates of fault dimensions. The epicentral location favors an intraplate setting because it is away from the continental-oceanic boundary and appears to lie within the continental crust of Vancouver Island, which overlies subducted oceanic lithosphere. However, the tectonic forces that caused the earthquake probably result from the interplate dynamics of the subduction zone.

● 2.5-5 Balderman, M. A. *et al.,* **The 1852 Fort Yuma earthquake,** *Bulletin of the Seismological Society of America,* 68, 3, June 1978, 699–710.

A major earthquake was reported near Yuma, Arizona, in Nov. 1852. Because of the sparse population and frontier conditions in the region, reports of the earthquake were incomplete and inaccurate. Subsequent accounts in historic earthquake catalogs repeated erroneous reports on the data, location, and intensity of the Fort Yuma earthquake. Review of original earthquake accounts indicates that the earthquake occurred about noon on Nov. 29, 1852. Analysis of the regional geology suggests that the earthquake was associated with the seismically active Salton Trough. Comparison of the effects of the Fort Yuma earthquake with those of subsequent large earthquakes in the region indicates that the event probably was located about 25 to 50 miles southwest of Yuma and had a probable magnitude of 6 to 7.

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

● 2.5-6 Cvijanovic, D. and Prelogovic, E., **The great Dubrovnik earthquake 1667,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-02, 1978, 9–16.

The earthquake of Apr. 6, 1667, with the epicenter in the Adriatic near Dubrovnik is one of the strongest earthquakes ever to have occurred in Yugoslavia. The damage in Dubrovnik is a classical example of the effects of seismic forces on various geological formations. The major destruction was in the part of the city where the soil was composed of loose material. The major tectonic and seismic activity was in the block from Ston to Cavtat, where regional faults and zones of increased seismic activity converge. In this area, the seismotectonic processes are such that earthquakes of magnitudes 6.5 to 7 are to be expected.

● 2.5-7 Arsovski, M. and Mihailov, V., **Effects of the Friuli earthquakes 1976 in Yugoslavia related to seismotectonic condition,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-36, 1978, 275–282.

The earthquakes that occurred in the Friuli, Italy region, during 1976 are directly related to the known seismogenic zone Gemona-Tolmezzo. This zone has been characterized by extensive geological rearrangements in recent time. It is manifested by the uplifting of Alpine structures from the Sarmatian up to the present of more than 2500 m and by the crushing and relative displacement of some blocks. At the same time, the Venetian depression, i.e., the Lombardian valley, has been sinking by as much as 2000 m. The region is the crossing zone for regional longitudinal faults with a transversal faulting zone occurring in the valley of the Tagliamento River. The intensive seismic activity during 1976 and the accelerograms recorded in the Yugoslavian area are in good correlation with the fault stretching and the geological structure of the region. The values of the recorded accelerations at Breginj and Kobarid are directly related to the Idrial fault activity in the direction of Dinaride and the submeridial direction faults representing transversal ruptures with respect to the main direction. The acceleration values recorded at Robic indicate a high degree of attenuation of ground motion on the monolithic block.

● 2.5-8 Horner, R. B. *et al.*, **Focal parameters of the July 12, 1975, Maniwaki, Quebec, earthquake—an example of intraplate seismicity in eastern Canada,** *Bulletin of the Seismological Society of America,* 68, 3, June 1978, 619–640.

The Maniwaki earthquake of July 12, 1975, occurred in a diffuse, poorly understood zone of significant seismicity in western Quebec. A field survey detected 14 aftershocks ranging from M_L -2 to M_L 1 in a 4-day period following the main shock. Main shock and aftershock activity occurred within an active volume of about 1 km diam located at 46° 27-1/2'N, 76° 17'W, at a depth of 17 km, with an estimated uncertainty of 2 km on all three hypocentral parameters.

Travel-time curves for P_n, P_1, S_n, and L_g phases yielded apparent velocities of 8.26 ± 0.02 km/sec (226 to 1165 km), 6.19 ± 0.09 km/sec (116 to 480 km), 4.72 ± 0.02 km/sec (364 to 1165 km), and 3.61 ± 0.01 km/sec (125 to 1165 km), respectively. P travel times to stations on the Canadian Shield at epicentral distances of less than about 2200 km were consistently earlier than predicted by the P curve of Herrin et al., suggesting that a P curve for the Canadian Shield by Hashizume might be more appropriate.

Body-wave magnitude m_b was calculated to be 4.2 ± 0.2 from stations for which $\Delta > 2400$ km. In good agreement was Nuttli's m_b (L_g) magnitude, calculated to be 4.1 ± 0.2. The coefficient of anelastic attenuation of vertical-component L_g waves of about 1-sec period was calculated to be 0.06 ± 0.02 deg^{-1} and again demonstrated the applicability of Nuttli's formula for earthquakes in eastern Canada.

The P-nodal solution indicated a predominance of thrust motion on a plane striking N64°W and dipping 65°SW or on a poorly defined plane confined between N34°W and N120°W and dipping 25° to 40° to the north. The deviatoric pressure axis was nearly horizontal in a SW to S direction. Seismic moment, average fault dislocation, and stress drop in the main shock were calculated to be 1.7 x 10^{22} dyne-cm, 6 cm and 50 bars, respectively. The small source dimensions, small average dislocation, and mid-crustal focal depth may explain the absence of active surface structures.

● 2.5-9 Acharya, H. K., **Mindanao earthquake of August 16, 1976: preliminary seismological assessment,** *Bulletin of the Seismological Society of America,* 68, 5, Oct. 1978, 1459–1468.

The Mindanao earthquake of Aug. 16, 1976, caused considerable loss of life, primarily because of the tsunami which followed the earthquake. The earthquake occurred in an area of high seismicity and poorly understood tectonics. P-wave first-motion study indicates that the fault movement was of the thrust type with the fault plane trending northwest (N25W) and dipping 24NE. The aftershocks of this earthquake trended northwest. The location of the earthquake on the inner wall of the Celebes Sea trench indicates its association with underthrusting. The extent of this zone of underthrusting, however, is not clear.

● 2.5-10 Sieh, K. E., **Slip along the San Andreas fault associated with the great 1857 earthquake,** *Bulletin of the*

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Seismological Society of America, **68**, *5*, Oct. 1978, 1421–1448.

Historical records indicate that several meters of lateral slip along the San Andreas fault accompanied the great 1857 earthquake in central and southern California. These records, together with dendrochronological evidence, suggest that the rupture occurred along 360 to 400+ km of the fault, including several tens of kilometers of the currently creeping reach in central California. Geomorphic expressions of late Holocene right-lateral offsets are abundant along the 1857 rupture. Along 300 kilometers of the 1857 rupture, between Cholame and Wrightwood, the youngest discernible offset ranges from 3 to 9 1/2 m. That the fault has been dormant since 1857 almost certainly indicates that this latest offset was created in 1857. Fault slip apparently associated with the 1857 earthquake varies in a broadly systematic way along the trace of the fault. It is relatively uniform along each of several long segments, but changes abruptly in value between these segments. This nonuniform displacement pattern may imply that some segments of the fault rupture more frequently or experience a slower long-term slip rate than others. The 1857 offsets indicate a seismic moment, m_o, between 5.3 and 8.7 x 10^{27} dyne-cm, assuming a 10- to 15-km depth of rupture and relatively uniform slip as a function of depth. A comparison with the rupture length, average slip value, and tectonic setting of the California earthquake of 1906 (M_S = 8 1/4) indicates a value of M = 8 1/4+ for the 1857 event.

● **2.5-11** Gawthrop, W., **The 1927 Lompoc, California earthquake,** *Bulletin of the Seismological Society of America*, **68**, *6*, Dec. 1978, 1705–1716.

The Lompoc earthquake (M_S = 7.3) of Nov. 4, 1927, which was originally located 80 km west of Point Arguello, has been relocated much closer to the coast of central California near Point Sal. *P*-wave arrival times at regional and teleseismic distances are used to determine the epicenter at 34.9°N and 120.7°W, near the Hosgri fault, with a 52-km major axis for the 95% confidence ellipse. This location is in close agreement with arrival times of several phases at seismographs located at Berkeley and Mount Hamilton. *S-P* time intervals from the first 36 hr of aftershocks recorded at Santa Barbara constrain the limits of the aftershock zone and seem to indicate a near coastal location of the fault rupture.

● **2.5-12** Hartzell, S. H., Brune, J. N. and Prince, J., **The October 6, 1974 Acapulco earthquake: an example of the importance of short-period surface waves in strong ground motion,** *Bulletin of the Seismological Society of America*, **68**, *6*, Dec. 1978, 1663–1677.

The Acapulco earthquake of Oct. 6, 1974 (m_b = 5.0, M_S = 4.75) resulted in 0.5 g accelerations in Acapulco, about 35 km from the epicenter. Extrapolation of the peak acceleration to the source region gives a near source acceleration of at least 1.0 *g*. If the teleseismically estimated source depth of 51 km is assumed, the Acapulco accelerogram must be interpreted as composed primarily of body waves. This assumption yields a moment estimate of 3.3 x 10^{23} dyne-cm and a stress drop of 1.5 kbar. However, strong evidence indicates that the source depth is only about 1.0 km and that the record is composed mainly of high frequency (1.0 to 4.0 Hz) surface waves. The character of the record is that of a normally dispersed surface wave. The relatively simple form and high acceleration may be attributed to the highly rigid crystalline rock in the region. The three-component record is fitted by summing the fundamental and the first higher mode Rayleigh and Love waves using a model consisting of a single layer over a homogeneous halfspace. The results are also checked using a direct wave-number integration program developed by Apsel and Luco. The moment estimate from the surface-wave synthetics is 2.0 x 10^{23} dyne-cm.

● **2.5-13** Herrmann, R. B., Cheng, S.-H. and Nuttli, O. W., **Archeoseismology applied to the New Madrid earthquakes of 1811 to 1812,** *Bulletin of the Seismological Society of America*, **68**, *6*, Dec. 1978, 1751–1759.

Recent studies of larger eastern North America earthquakes, together with seismicity and focal mechanism studies of the New Madrid seismic zone, permit estimates of static vertical displacements associated with the 1811 to 1812 New Madrid earthquakes. A comparison of observed and theoretically predicted vertical displacements is inconclusive because the historical record lacks detail, and because of the physical characteristics of the region where the earthquakes occurred. However, estimates are made of the seismic moment, fault area, and fault displacement. Given the inherent errors of the estimates, the parameters M_S, M_o, and fault area are consistent with the Kanamori and Anderson study of the interrelationship of these parameters for worldwide earthquakes. A stress drop on the order of 60 to 100 bars seems reasonable. These estimates will be useful for the numerical estimation of ground motion.

● **2.5-14** Rankin, D. W., **Studies related to the Charleston, South Carolina, earthquake of 1886–a preliminary report,** *Professional Paper 1028*, U.S. Geological Survey, Washington, D.C., 1977, 204.

The seismic history of the southeastern United States is dominated by the 1886 earthquake near Charleston, South Carolina. An understanding of the specific source and the uniqueness of the neotectonic setting of this large earthquake is necessary to properly assess seismic hazards in the southeastern U.S. Such knowledge will also contribute to the fundamental understanding of intraplate earthquakes and will aid indirectly in deciphering the evolution of Atlantic-type continental margins. The 15 chapters in this volume report on the first stage of an ongoing multidisciplinary study of the Charleston earthquake of 1886.

● 2.5-15 Mihailov, V., ed., **Friuli earthquakes 1976: seismological, tectonic and engineering-seismological aspects** (in English and Serbian), *58,* Inst. of Earthquake Engineering and Engineering Seismology, Univ. of Skopje, Yugoslavia, May 1978, 66.

● 2.5-16 Basili, A. *et al.*, **A stochastic analysis of 1976 Friuli earthquake seismic data,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III,** 737–758. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Stochastic analysis techniques are applied to the results of an investigation of the time distribution of 836 shocks which occurred during the 1976 Friuli earthquake sequence.

● 2.5-17 Ambraseys, N. N., **A re-appraisal of the Friuli 1976 & Romanian 1977 earthquakes,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III,** 773–789. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper points out that it is often the case that, after destructive earthquakes such as those in Friuli, Italy, Romania, or San Fernando, California, the ensuing thorough and interdisciplinary study of the event demonstrates how little was known about the seismicity of the affected area before the event and how much could have been learned had such a study been carried out earlier. Typical examples are the Friuli and the Romanian earthquakes, which are examined in this paper.

● 2.5-18 Finetti, I. *et al.*, **Seismic evolution of the Friuli earthquake (1976-1977),** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. II,** 400–425. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Simulated results of the Friuli May 6, 1976, earthquake are presented based on historical and seismological data collected by the Osservatorio Geofisico Sperimentale, Trieste. The epicentral and hypocentral distributions calculated from the networks and from Trieste WWSS station data are discussed. The Latisana 1975-1976 earthquakes are interpreted as the foreshocks of the May 6 principal event and the larger shock parameters are roughly calculated. A correlation between the hypocenters and the geodynamic structure present in the region is attempted.

● 2.5-19 Basili, M. *et al.*, **Estimate of seismic moment and other seismic parameters of some 1976 Friuli earthquakes,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. II,** 387–399. (For a full bibliographic citation, see Abstract No. 1.2-7.)

By using Brune's theory, the seismic moment, the linear dimensions of the fault, the dislocation and the stress drop of some of the strongest earthquakes of the 1976 Friuli sequence are obtained. Accelerograph records are analyzed for this purpose. Accelerograms are digitized and processed by means of a computer program which filters out high- and low-frequency components, corrects instrument and distance frequency-dependent effects and computes ground displacement and the Fourier spectrum. The obtained results show stress drop values that vary in the interval from 11-115 bars. As for the dimension of the fault, the equivalent rays have values between 2 and 8 km which is in agreement with the aftershock area.

● 2.5-20 Martinis, B. and Cavallin, A., **Ground cracks caused by the Friuli earthquake, 1976, from M. Cuarnan and Tremugna Valley,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. I,** 87–102. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Among the ground cracks caused by the Friuli earthquake, those located on the southern slope of Mount Cuarnan and in the Tremugna Valley have been investigated. In the first locality, the ground cracks were increased by the seismic shocks of Sept. 15, 1977. Areas in which ground cracks occurred have been surveyed in detail, and surficial deposits, bedrock, and morphological characteristics have been mapped on a large scale. These ground cracks have been interpreted as originating as a result of landslides triggered by the earthquake.

● 2.5-21 Weber, C. and Courtot, P., **The Friuli earthquake (Italy, 6 May 1976) in its seismotectonic context** (Le seisme du Frioul (Italie, 6 mai 1976) dans son contexte sismotectonique, in French), *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. I,** 41–53. (For a full bibliographic citation, see Abstract No. 1.2-7.)

A better understanding of the mechanism of the May 6 Friuli earthquake can now be developed by considering the consistency of the elements of the entire set of available data. The data include: (1) structural criteria, (2) interpretation of the satellite images, (3) recent tectonics, (4) historical seismicity, (5) macroseismic observations, (6) study of the aftershocks of the two main earthquakes, (7) fault-plane solutions. Conclusions from these data indicate that the Friuli earthquakes are related to a crustal compression of approximately NW-SE direction; thus, pre-existing faults have been reactivated. The faults are of two types: (1) left-lateral strike-slip, clearly identified on Landsat images and

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

observed on the ground along the right bank of the Tagliamento River and (2) low-angle thrusts, where a great number of aftershocks occurred. The complexity of the faulting explains the difficulty in interpreting the fault-plane solutions that have been computed. A new focal mechanism is given for the main shock. It shows left-handed strike-slip which could be related to the Tagliamento and Buia fault system. Fault-plane solutions for the aftershocks mostly indicate thrust fault mechanisms.

● 2.5-22 Cagnetti, V. and Console, R., **Space-time distribution of the 1976 Friuli earthquake shocks,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 186-222. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Results obtained by hypocentral determination of 700 shocks of the Friuli earthquake have been examined. Special attention has been devoted to the main shock. A comparison between focal parameters determined by analytical methods and macroseismic methods has been carried out. The time and space evolution of the phenomenon has been examined by means of an array of local stations which allowed the determination of the hypocenters of about 700 aftershocks. An analytical method based on the S-P time interval has been employed, assuming a K-value of 7.5 km/sec. An evaluation of experimental errors, performed by means of an original code, yielded an accuracy of ±2 km. The study of hypocentral migration has shown that seismic activity both preceded and followed an event of greater magnitude. Epicentral and hypocentral distributions plotted in order to depict the time evolution of the phenomenon are shown in intervals. The results show interesting features of the seismic period which warrant investigations of this type.

● 2.5-23 Delhaye, A. *et al.*, **Note on fault plane solutions relative to the major shocks and some aftershocks of the Friuli area during May to September 1976** (in French), *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 180-185. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Using short-period data recorded on the seismic network of France's Commissariat a l'Energie Atomique, similar data provided by Italian stations, and that supplied by the U.S. Geological Survey (either Pg, or Pn, or both phases), the authors have obtained fault plane solutions for some of the earthquakes that occurred in the Friuli area during 1976. In many cases, the lack of information on initial movements combined with the unsatisfactory azimuthal distribution of reporting seismic stations does not lead to clear solutions. However, in certain cases, in particular those involving major shocks, sufficient data was available to arrive at probable solutions.

● 2.5-24 Delhaye, A., Massinon, B. and Rigaud, J. F., **Seismicity of the Friuli area recorded by a French seismic network from May to October 1976** (in French), *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 165-179. (For a full bibliographic citation, see Abstract No. 1.2-7.)

The stations of the permanent seismic network of France's Commissariat a l'Energie Atomique recorded a significant part of the seismic activity that occurred in the Friuli area between May and Oct. 1976. The stations are located between 500 km to 1,100 km from the area. The locations of major earthquakes and evaluations of the magnitudes (M_L) are given. Some aftershock information also is given. Frequency-magnitude distributions for the two major shocks and their aftershocks are presented. The number of aftershocks recorded is limited by a detection threshold of magnitude 2.5. The results for 354 events are discussed. A comparison is made between seismic activity versus time for the first and second earthquake series.

● 2.5-25 Giuliani, P., **Presentation of the Friuli earthquake,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. I, 19-24. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper briefly describes the seismological aspects of the 1976 Friuli seismic period and the seismic instrumentation of the area. Included are an intensity map, an isoseismal map, and two maps showing the locations of the Italian strong-motion recording network.

2.5-26 Sobouti, M., Eshghi, I. and Mostaanpour, M. M., **Shamil-Siahou earthquake "north-east of Bandar-Abbas" of 21st March, 1977,** *Journal of Geophysics,* 44, *6,* 1978, 663-674.

This paper examines the properties of the Shamil-Siahou earthquake obtained by field observations performed by such organizations as the Iranian Seismological Stations and the International Seismological Center. Discussed are preliminary studies of regional seismicity, ground movements, isoseismal maps, specifications of the major shocks and aftershocks, and structural damage.

● 2.5-27 **The Izu-Oshima-kinkai earthquake of 1978** (in English or Japanese), *Bulletin of the Earthquake Research Institute, University of Tokyo,* 53, *Part 3,* 1978, 613-1133.

The following papers in this special issue are pertinent to earthquake engineering. None of these papers are abstracted in this volume of the *AJEE.* Those papers with asterisks after the titles (the first two) are written in English; all other papers are written in Japanese with English abstracts.

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Summary of the static and dynamic parameters of the Izu-Oshima-Kinkai earthquake of January 14, 1978,° Shimazaki, K. and Somerville, P.—*Surface faulting associated with the 1978 Izu-Oshima-kinkai earthquake,°* Tsuneishi, Y., Ito, T. and Kano, K.—*Seismic activities before and after the Izu-Oshima-kinkai earthquake of 1978,* Tsumura, K. *et al.*—*Distribution of foreshocks and aftershocks of the Izu-Oshima-kinkai earthquake of 1978 by semi-automatic processing,* Kanjo, K., Nakamura, I. and Tsumura, K.—*Aftershock activity of the Izu-Oshima-kinkai earthquake of 1978 and anomalous structure beneath Oshima-Island, Japan,* Kasahara, J. *et al.*—*Spectral analysis of seismic waves for a sequence of foreshocks, main shock and aftershocks: the Izu-Oshima-kinkai earthquake of 1978,* Tsujiura, M.—*Aftershock observation of the Izu-Oshima-kinkai earthquake of 1978 with a strong-motion accelerograph and the maximum accelerations during the main shock,* Tanaka, T. *et al.*—*On the shear wave underground structure of Izu Peninsula,* Kudo, K. *et al.*—*Seismic intensity and damage distribution of the earthquake of January 14, 1978 on the east coast of Izu Peninsula, central Honshu, Japan, investigated by questionnaire survey,* Kayano, I.—*Semidiurnal and diurnal variations in earthquake swarm activity in the Izu Peninsula during the period from 1975 to 1978,* Shimada, S.—*Precursory changes in water level at Funabara and Kakigi before the Izu-Oshima-kinkai earthquake of 1978,* Yamaguchi, R. and Odaka, T.—*Tsunami source of the Izu-Oshima-kinkai earthquake of 1978,* Hatori, T.—*A numerical experiment for the tsunami accompanying the Izu Oshima-kinkai earthquake of 1978,* Aida, I.—*Gravity change during the Izu-Oshima-kinkai earthquake of 1978,* Hagiwara, Y. *et al.*—*Anomalous secular variation in the geomagnetic total intensity on Oshima Volcano,* Yukutake, T. *et al.*—*Changes in the geomagnetic total force intensity associated with the anomalous crustal activity in the eastern part of the Izu Peninsula (2)—the Izu-Oshima-kinkai earthquake of 1978,* Sasai, Y. and Ishikawa, Y.—*Observations of short-period geomagnetic variations at Nakaizu (1),* Honkura, Y. and Koyama, S.—*On a relation between anomalies in the geomagnetic and telluric fields observed at Nakaizu and the Izu-Oshima-Kinkai earthquake of 1978,* Honkura, Y.—*Observations of electric self-potential at Nakaizu (1),* Koyama, S. and Honkura, Y.—*The earth resistivity measurements along the Inatori-Omineyama fault in the eastern part of the Izu Peninsula,* Yukutake, T. *et al.*—*Geoelectric survey around a fault in Izu Peninsula,* Utada, H. *et al.*—*Time variations observed in the earth resistivity on the Oshima Volcano before the Izu-Oshima-Kinkai earthquake on January 14, 1978,* Yukutake, T. *et al.*—*Resistivity change at Aburatsubo associated with the Izu-Oshima-kinkai earthquake of 1978—a record of the 73 Hz resistivity variometer,* Yamazaki, Y.—*Variations in chemical composition of thermal water before and after the 1978 Izu-Oshima-kinkai earthquake, at Tokunage-minami and Tsukigase in the Izu Peninsula,* Takahashi, H. and Tsuneishi, Y.—*Surface ruptures associated with the Izu-Oshima-kinkai earthquake of 1978,* Murai, I., Matsuda, T. and Nakamura, K.—*Damage, seismic intensities, and earthquake faults by the Izu-Oshima-kinkai earthquake of 1978,* Murai, I., Tsunoda, N. and Tsujimura, Y.—*Slope collapses along the main roads of the Izu Peninsula caused by the 1978 Izu-Oshima-kinkai earthquake,* Tsuneishi, Y., Ito, T. and Kano, K.—*Investigation of the activity of the Oshima Volcano associated with the Izu-Oshima-kinkai earthquake of 1978,* Shimozuru, D. *et al.*—*A report on the damage to civil engineering structures caused by the Izu-Oshima-kinkai earthquake of 1978,* Hakuno, M., Fujino, Y. and Katada, T.

● **2.5-28** Hoffman, J. P. and Northrop, S. A., **The Dulce, New Mexico earthquake, January 23, 1966,** *Earthquake Notes,* **48,** *4,* Oct.-Dec. 1977, 3-20.

On Jan. 22, 1966, an earthquake of magnitude 5.5 occurred in north-central New Mexico near the town of Dulce. There was damage to homes and school buildings, but there were no injuries. Intensity at Dulce was VII on the Modified Mercalli Intensity Scale. Many aftershocks followed the main event, and on January 29, three temporary seismograph stations were installed in the area.

● **2.5-29** Lee, W. H. K. *et al.,* **A preliminary study of the Santa Barbara, California, earthquake of August 13, 1978 and its major aftershocks,** *Circular 797,* U.S. Geological Survey, Arlington, Virginia, 1978, 11.

The M_L 5.1 Santa Barbara earthquake of Aug. 13, 1978, occurred at latitude 34° 22.2′N., longitude 119° 43.0′4 km south of Santa Barbara, California, at a depth of 12.5 km in the northeast Santa Barbara Channel, part of the western Transverse Ranges geomorphic-structural province. This part of the province is characterized by seismically active, east-trending reverse faults and rates of coastal uplift that have averaged up to about 10 m/1000 years over the last 45,000 years.

No surface rupture was detected onshore. Subsurface rupture propagated northwest from the main shock toward Goleta, 15 km west of Santa Barbara, where a maximum acceleration of 0.44g was measured at ground level and extensive minor damage occurred; only minor injuries were reported. A fairly well constrained fault-plane solution of the main shock and the distribution of the aftershocks indicate that left-reverse-oblique slip occurred on west-northwest-trending, north-dipping reverse faults; inadequate dip control precludes good correlation with any one of several mapped faults. Had the earthquake been larger with rupture propagating to the southeast or a greater distance to the northwest, it could have posed a hazard to oilfield operations. The fault-plane solution and aftershock pattern closely fit the model of regional deformation, and the solution closely resembles those of five previously mapped events located within a 15-km radius.

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2.6 Seismic Water Waves

● 2.6-1 Everingham, I. B., **Tsunamis in Papua New Guinea**, *Science in New Guinea*, 4, *1*, 1976, 10–20.

A preliminary catalog of tsunamis that occurred in Papua New Guinea from 1768 to 1975 has been compiled. Information for this catalog was taken from published literature, including local newspapers, government administration and public works reports, volcanologic and geophysical observatory records, and reports by individuals. Fifty-eight Papua New Guinean tsunamis are listed; fifty of them occurred after 1900. A suggested precaution against tsunami damage is to construct buildings about 2 to 3 m above the highest tide level.

● 2.6-2 Habercom, Jr., G. E., ed., **Tsunamis: a bibliography with abstracts: search period covered 1964 - November 1977,** National Technical Information Service, Springfield, Virginia, Dec. 1977, 197. (Accession No. NTIS/PS-77/1165)

Prediction and effects of tsunamis are reviewed. Also included are methods of preventing damage caused by tsunamis. Harbors, river basins, and coastal regions are among the areas investigated. This updated bibliography contains 193 abstracts, 27 of which are new entries.

● 2.6-3 Kawahara, M., Takeuchi, N. and Yoshida, T., **Two step explicit finite element method for tsunami wave propagation analysis,** *International Journal for Numerical Methods in Engineering,* 12, *2,* 1978, 331–351.

Tsunamis are analyzed numerically by applying the finite element method. The analysis is based on the shallow water wave equation. To discretize time, a two-step explicit method is used. The method is an extension of the Lax-Wendroff finite difference method. The present finite element method is used for the analysis of the Tokachi-oki earthquake tsunami and is compared with the tide gauge records. The paper concludes that the method presented is suitable for the prediction of tsunami wave propagation.

● 2.6-4 Miloh, T. and Striem, H. L., **Tsunamis effects at coastal sites due to offshore faulting,** *Tectonophysics,* 46, *3/4,* Apr. 28, 1978, 347–356.

Unusually large waves (tsunamis) triggered by submarine tectonic activity, such as a fault displacement in the sea bottom, may have considerable effect on a coastal site. The possibility of tsunamis occurring at the southern coast of Israel as a result of a series of shore-parallel faults about 20 km offshore is examined in this paper. The analysis relates the energy or the momentum imparted to the body of water by a fault displacement of the sea bottom to the energy or the momentum of the water waves thus created. The faults off the Ashdod coast may cause surface waves with amplitudes of about 5 m and periods of about 1/3 hr. It is stated that, because of the downward movement of the faulted blocks, the first and the predominant effect at the shore would be a recession of the sea level rather than a flood. This suggestion is in agreement with some historical reports. The analysis might be of interest to those designing coastal power plants.

● 2.6-5 Aida, I., **Reliability of a tsunami source model derived from fault parameters,** *Journal of Physics of the Earth,* 26, *1,* 1978, 57–73.

Numerical calculations of tsunami generation and propagation are carried out for five earthquakes which occurred off the Pacific coast of the Tohoku and Hokkaido districts of Japan. The tsunami sources used in the calculations are the vertical displacement fields of the sea bottom derived from the seismic fault models for each earthquake. Water surface disturbances are computed by a finite difference hydrodynamical method with finer grids in shallower water. The comparison of the computed tsunami behavior with available tsunami records shows that the distribution of observed tsunami heights can be explained in the first approximation by seismic fault models and the observed heights are 1.2 to 1.6 times larger than the computed heights. An example is presented of a fault model inferred from seismic data which is not suitable for a tsunami source.

● 2.6-6 Murty, T. S., **Seismic sea waves: tsunamis,** *Fisheries Research Board Bulletin 198,* Fisheries and Marine Service, Canada Dept. of Fisheries and the Environment, Ottawa, 1977, 337.

This report synthesizes the current knowledge of tsunamis. Although it is directed primarily to oceanographers, information valuable to researchers in other disciplines is also included. The book deals with phase and amplitude dispersion problems and the Ursell parameter which delineates various regimes of dispersion. The classical Cauchy-Poisson problem is introduced and the subsequent developments in the field of water-wave generation caused by explosions are discussed. Tsunami generation by earthquakes and seismic sources such as volcanic explosions and nuclear explosions is considered. Some related phenomena such as landslides and turbidity currents are also included. The propagation of tsunamis across the oceans is discussed. The influences of refraction, diffraction, and scattering are examined, and the problem of trapping tsunami energy by islands and shoals is examined in detail. Coastal tsunami problems such as the forerunner, the initial withdrawal of water, the secondary undulations, and the tsunami bore are included, as well as the influence of resonance on tsunamis. Tsunamis in various parts of the world are described. Tsunami warning systems, instrumentation, and protection measures are discussed. Background information on seismology is provided in the appendix in microfiche form.

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● 2.6-7 Cox, D. C. and Morgan, J., **Local tsunamis and possible local tsunamis in Hawaii,** *HIG-77-14, Environmental Center CN: 0014,* Hawaii Inst. of Geophysics, Univ. of Hawaii, Honolulu, Nov. 1977, 118.

2.7 Artificially Generated Ground Motions or Seismic Events

● 2.7-1 Higgins, C. J., Johnson, R. L. and Triandafilidis, G. E., **The simulation of earthquake-like ground motions with high explosives,** *CE-45(78),* Bureau of Engineering Research, Univ. of New Mexico, Albuquerque, July 1978, 563.

Experimental data from actual or simulated earthquakes are needed to verify or improve earthquake-resistant design techniques. Simulations are needed because data from actual earthquakes are limited and will continue to be limited because of the uncertainties of time and place of occurrence. An investigation was made of the technical and economic feasibility of simulating earthquake-like ground motions with high explosives. This form of simulation appears most applicable to evaluations of soil-structure interaction when the structural response is coupled with the response of the medium through which the ground motion waves propagate.

Eight areas were investigated: (1) Potential simulation methods were identified. (2) An approach was developed for simulation criteria. (3) Existing ground motion data were analyzed. (4) Because the data base was not sufficient for a high confidence assessment of feasibility, a numerical calculation approach was developed to expand the data base, in which over 30 one- and two-dimensional calculations were performed to provide insight into explosive ground motion phenomena and to reveal relationships between the governing parameters. (5) Numerical calculations aimed at enhancing ground motions from explosive sources were performed. (6) The data and calculation results were synthesized into prediction relations. (7) The application of explosives to simulate an earthquake-like environment to a specific structure was studied. (8) The economic feasibility of using explosives to simulate earthquake-like systems was considered.

The investigation concludes that explosive simulation of earthquake-like ground motions on engineering systems is technically feasible. Explosives in various arrays can produce motion amplitudes and frequency content which are in the range of those expected in large earthquakes. Further, the wave structure from planar explosive arrays contains significant shear wave contributions to the horizontal motion. This is similar to what is thought to occur in actual earthquakes. Multiple cycles of motion and long-time durations can be obtained from multiple, sequenced explosions. Explosive ground motions in dry alluvial materials can be predicted with reasonable confidence using methods developed in the investigation.

2.7-2 Bell, M. L. and Nur, A., **Strength changes due to reservoir-induced pore pressure and stresses and application to Lake Oroville,** *Journal of Geophysical Research,* 83, *B9,* Sept. 10, 1978, 4469-4483.

The association of a significant increase in seismic activity with the filling of some large water reservoirs is well documented. One possible case is the earthquake sequence at Oroville, California, in 1975. It has been suggested that this activity may be triggered on faults close to failure by the weight of the water, the increase in pore pressure, or both. Two-dimensional halfspace models with surface loading are used to study the change in strength produced by these mechanisms for thrust, normal, and strike-slip faulting. For the case of the water weight alone, the strength increased across fault planes, dipping as in the Oroville sequence. It is concluded that the water load alone is an unlikely mechanism. The inclusion of pore pressure effects in these models, however, is shown to be very encouraging. Using the Biot linearized quasi-static elasticity theory for fluid-infiltrated porous materials, two types of loaded halfspace models were studied. The first was homogeneous with respect to permeability and found to produce broad zones of weakening. The second type included a fault zone of different permeability. This model intensifies the magnitude and broadens the zone of strength drop if the fault zone is highly permeable in relation to the rest of the halfspace. For fault dips roughly corresponding to the Oroville situation, it was found that, although weakening occurs for ambient stresses favoring either thrust or normal faulting, the magnitude and breadth of strength drop were significantly greater for normal faulting. Similar effects were observed for strike slip faulting. It was also found that all types of models developed significant zones of weakening very rapidly, permitting reasonable values of permeability to be estimated. The case of the impervious reservoir bottom was examined with significantly differing results. Just as in the permeable case, zones of weakening were initially developed. However, in the impermeable case, these dissipated with time, eventually reaching the same strength distribution as that of the water weight alone. Thus, with sufficiently slow impoundment the impervious reservoir may not weaken at all, whereas the permeable reservoir will continue to weaken in time. The results also show that rapid unloading may cause instantaneous crustal weakening because of excess pore pressure. Although the models are simplified, it is interesting to apply them to the case of Lake Oroville. Using reasonable parameters, strength drops for normal faulting of 8-14 bars were calculated and compared favorably to the fluid injection experiments at Rangely and Matsushiro. The observed lag time between initial impoundment and seismicity yielded a permeability of 0.2 mdarcy for the homogeneous

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model and 20 mdarcy for the greater strength drops produced by the heterogeneous model. Both of these are reasonable rock values. If the period of rapid filling is assumed to have triggered the activity, then the permeability was found to be 3.6 mdarcy for the homogeneous model and 360 mdarcy for the heterogeneous model, the latter of which is appropriate for fractured rock. It is concluded that the pore pressure trigger mechanism is promising and that the methods of this paper may be extended to three dimensions to study reservoirs in more detail. The mechanism is limited, however, by the lack of knowledge of, first, the ambient pore pressure in situ and, second, the in-situ permeability, coupling parameters, reservoir bottom permeability, and local tectonic stress. Perhaps the most important implications of the results are the presence of water to depths of 10 km or more in the crust. Thus, at least in some places, the crust may be weak, and tectonic stresses low. This also suggests an important potential for geothermal energy at great depth in the crust.

● 2.7-3 Yaralioglu, M., **Seismicity of Keban Dam reservoir area and its vicinity after impounding of the dam,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-19, 1978, 135-142.

The Keban Dam in the eastern part of Turkey has a drainage area of 64.1 km^2, a reservoir capacity of about 31 x 10^9 m^3, and a height of 220 m. Because it is one of the largest in the world, seismic investigations have been carried out since 1973. Seismic recordings from six seismic stations around the reservoir area reveal that inactive fault zones have become active after impounding and that earthquake activity has increased. The local microearthquake magnitude was found to be a maximum of 3.5; but the majority of the earthquakes recorded have M_L magnitudes of $1.5 \leq M_L \leq 2.5$. Recorded microearthquakes generally have been scattered along the NW-SE and NE-SW fault zone directions. Because of stress buildup caused by impounding, faults partially within the reservoir area experienced more seismic effects than faults outside the area. The induced microearthquakes are estimated to have focal depths of 5 to 10 km.

● 2.7-4 Leblanc, G. and Anglin, F., **Induced seismicity at the Manic 3 reservoir, Quebec,** *Bulletin of the Seismological Society of America,* **68,** *5,* Oct. 1978, 1469-1485.

Six weeks after filling of the Manic 3 reservoir was begun, a long sequence of induced earthquakes began. The main shock occurred on Oct. 23, 1975 and was preceded by one month of foreshock activity. More than 1000 aftershocks followed in the next four months. After two years, the activity still persists, although the microshocks are substantially reduced in frequency and magnitude. Station MNQ, about 80 km from the activated source, served as an efficient monitor by providing data from which increasing induced seismicity was predicted and by evaluating the subsequent activity. Two portable networks were deployed around the source, one in 1975 and the other in 1976. The activity was very shallow, with an average value of 1.5 km, and the cluster of microearthquakes spread over an area of 4 by 4 km. No systematic spatial migration was observed. The activity appeared to be triggered by the water percolating through joint systems and along northwest oriented planes. Regional stresses and local structural and lithological inhomogeneities are suggested as the principal causes of the seismicity and not the dimensions of the reservoir and the water height.

● 2.7-5 Hays, W. W., King, K. W. and Park, R. B., **Duration of nuclear explosion ground motion,** *Bulletin of the Seismological Society of America,* **68,** *4,* Aug. 1978, 1133-1145.

This paper evaluates the duration of strong ground shaking that results from nuclear explosions and identifies some of the problems associated with the determination of the duration of shaking. Knowledge of horizontal ground shaking duration is important out to epicentral distances of about 44 km and 135 km, the approximate distances at which the ground shaking level falls to 0.01 g for nuclear explosions having yields of about 100 kt and 1,000 kt, respectively. Evaluation of the strong ground motions recorded from the event STRAIT (M_L = 5.6) on a linear array of five, broad-band velocity seismographs deployed in the distance range 3.2 to 19.5 km provides information about the characteristics of the duration of ground shaking. The STRAIT data show that: (1) the definition used for defining duration is very important; (2) the duration of ground acceleration, as defined in terms of 90 percent of the integral of the squared time history, increased from about 4 to 26 sec over the approximately 20 km distance range; and (3) the duration of ground velocity and displacement were slightly greater because of the effect of the alluvium layer on the propagating surface waves. Data from other events (e.g., MILROW, CANNIKIN, HANDLEY, PURSE) augment the STRAIT data and show that: (1) duration of shaking is increased by frequency-dependent site effects, and (2) duration of shaking, as defined by the integral of the squared time history, does not increase as rapidly with increase in yield as is indicated by other definitions of duration that are stated in terms of an amplitude threshold (e.g., bracketed duration, response envelopes). The available data suggest that the duration of ground acceleration, based on the integral definition, varies from about 4 to 40 sec for a 100 kt range explosion and from about 4 to 105 sec for a megaton range explosion in the epicentral distance range of 0 to 44 km and 0 to 135 km, respectively.

● 2.7-6 Buchbinder, G., **Earthquakes in a Quebec hydro development—earthquakes induced by reservoir filling:**

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the first documented in Canada, *Emergency Planning Digest,* **5,** *2,* Mar.-Apr. 1978, 2–5.

On Oct. 23, 1975, a magnitude 4.1 earthquake occurred 10 km upstream from the Manic 3 Dam, located on the Manicouagan River about 500 km northeast of Quebec City, Quebec. This paper describes the seismological studies conducted near the dam. It concludes that the earthquake was not caused by pressure from the load of water impounded by the dam but by fluid injection.

● 2.7-7 Withers, R. J., **Seismicity and stress determination at man-made lakes,** Woodward-Clyde Consultants, San Francisco, [1978], 241.

Two related models are proposed to explain the relationships among seismicity, water depth, loading history, and hydrologic conditions at an artificial lake. Both models involve fluid loads on layered halfspaces. The response in each case is determined most rapidly by Fourier transformation techniques. The models are laterally homogeneous, but, in spite of this simplification, they predict a number of observed seismic features. A model of a load on an elastic halfspace predicts many features, but does not provide time-dependent predictions. A similar calculation for a permeable layered structure predicts that initial seismicity will occur directly beneath a reservoir during its first filling. However, the region most susceptible to seismicity changes in position and time as the lake depth varies and may be offset from the lake. The response of a permeable structure can be expressed as a product of two terms: one evaluated at the particular time of interest, and the other a convolution-integral containing the rate of change of depth.

Examples of the calculations for various loading histories are given in two and three dimensions. For a two-dimensional lake model and an assumed filling history, seismic risk is shown to be a function of time and position with respect to the lake. Maintaining a constant water depth allows the region to stabilize slightly by permitting lobes of high pore pressure to diffuse. It is also shown that a partial draining and refilling sometime after the initial filling can cause extremely large stresses in the rock. In some instances, it is felt that draining and refilling may cause an increase in the regional seismicity.

2.7-8 Terashima, T. and Ozawa, K., **Abnormal variation of thermal water volume gushing from spa in Izu Peninsula, Japan** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **31,** *1,* Mar. 1978, 87–93.

It is suggested that the behavior of underground water plays an important role in triggering earthquakes. Studies are made in this paper on the variations of flow rate, temperature, and heat capacity of hot springs in the Izu Peninsula from 1968 to 1976. The patterns of these variations show good correlation with recent crustal movement and gravity variation in the area. It is concluded that variations in hot springs may be one seismic precursor.

● 2.7-9 Toppozada, T. R. and Cramer, C. H., **Ukiah earthquake, 25 March 1978: seismicity possibly induced by Lake Mendocino,** *California Geology,* **31,** *12,* Dec. 1978, 275–281.

The Lake Mendocino area has experienced the highest level of seismic activity of any area within a radius of 90 km of the lake. Initial impoundment of water in 1959 was immediately followed by an M 3.6 earthquake. Within 6 months an M 3.5 earthquake ensued. An earthquake of M 5.2 occurred in 1962, less than 4 months after the largest seasonal fluctuation in the lake's water level before the 1977-1978 season. This is the largest earthquake to occur within 90 km of Lake Mendocino during the past 80 yr. The greatest seasonal fluctuation in the lake's 20 yr history resulted from the drought of 1976-1977 and the rapid refilling in Dec. 1977. An M 4.5 earthquake followed this fluctuation in Mar. 1978. The important 1962 earthquake was relocated using the 1978 earthquake as the master event. Both the 1962 and 1978 earthquakes occurred within 11 km of Lake Mendocino, apparently on the extensive Maacama fault.

Lake Marathon in Greece is the only reservoir as shallow and as small as Lake Mendocino that is known to have induced earthquakes of M 5 or larger. Both reservoirs are located near active plate margins that have generated earthquakes of magnitudes greater than 8 during the 20th century. The initial impoundment of both reservoirs induced minor seismicity, but in both cases larger and more damaging earthquakes occurred several years after filling. At Lake Marathon the largest earthquake occurred 10 yr after filling; at Lake Mendocino the largest earthquake occurred 3 yr after filling and the second largest occurred 16 yr later. All these earthquakes immediately followed the largest seasonal fluctuations in lake level.

This pattern of the strongest earthquakes lagging several years after impoundment occurs not only at Lakes Marathon and Mendocino, but also at deeper reservoirs that are further removed from active plate boundaries. At Koyna (India), Oroville (California), and Vajont (Italy), the strongest earthquakes occurred 4 yr, 8 yr, and 3 yr after filling, respectively; and in each case the earthquakes followed record seasonal fluctuations in water level. At each of these five reservoirs the stronger earthquakes were preceded by foreshock activity.

2.7-10 Withers, R. J. and Nyland, E., **Time evolution of stress under an artificial lake and its implication for induced seismicity,** *Canadian Journal of Earth Sciences,* **15,** *9,* Sept. 1978, 1526–1534.

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The time history of the stress beneath a realistic artificial lake with a realistic loading history on a permeable lithosphere can be calculated by solving the consolidation equations for a uniform permeable medium. The evolution of stress conditions towards or away from a Mohr-Coulomb failure envelope illustrates that the highest risk of induced seismicity exists at initial loading and, in some cases, after a down-draw of the lake. The calculated histories depend crucially on hydrologic and geologic conditions which are very poorly understood at many artificial lakes. If the formation strengths are constant in the area of the lake, consolidation theory indicates that failure is most likely under the lake in strike-slip or normal fault regimes. If failure occurs because of loading on a thrust fault regime, it will occur at an offset from the lake.

● **2.7-11** Shima, E., Yanagisawa, M. and Zama, S., **On the deep underground structure of Tokyo metropolitan area** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 41, Nov. 1978, 321–328.

A project was begun in 1975 to clarify the deep underground structure of the Tokyo metropolitan area by means of the seismic refraction method. The first explosion, 500 kg of dynamite, was set off on Feb. 23, 1975, in Yumenoshima, the southernmost part of Tokyo's reclaimed land, and the resulting seismic waves were observed at 16 temporary stations along an area 30 km in length, northward from the shot point. Since then, six large explosions have been set off in Yumenoshima and once in Yoshikawa, at the north end of the first area. The resulting seismic waves have been observed at many stations in and around the metropolitan area. Observations of seismic waves resulting from five explosions set off by other researchers have also been carried out. An analysis shows that the P- and S-wave velocities of the base rock were 5.6 km/sec and 3 km/sec, respectively. The depth to the base rock was found to be 2.3–2.5 km. A map has been constructed of the metropolitan area in order to study the three-dimensional characteristics of the base rock. From the map, it can be determined that the base rock is deepest (3.6 km) in the northwest part of the twenty-three wards of Tokyo. The base rock apparently is very shallow or exposed at the ground surface west of Takao and northwest of Ogose.

● **2.7-12** Higgins, C. J., Simmons, K. B. and Pickett, S. F., **A small explosive simulation of earthquake-like ground motions**, *Earthquake Engineering and Soil Dynamics*, Vol. I, 512–529. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A small experiment, assigned the test name MINI-SIMQUAKE, was conducted to verify the technical feasibility of simulating earthquake-like ground motions by sequential detonation of closely spaced planar arrays of high explosives. The experiment contained two explosive arrays which were detonated 0.3 sec apart. Ground motions and the response of a small cylindrical structure were measured with accelerometers and velocity gages. In addition, an angular displacement measurement was taken in the structure. The experiment demonstrated that enhancement of the time duration and number of motion cycles of explosive experiments is feasible and practical with time-sequenced explosions. The behavior of arrays indicated that careful attention must be paid to array separation and firing system details. Since the measured ground motions significantly expanded the available data base for planar explosions, it appears that ground motions from planar experiments in alluvium can be predicted with a reasonable level of confidence. The experiment induced strong rocking behavior in the model structure which exhibited a 5-to-7 factor lower fundamental rocking frequency than estimated based on low strain level soil properties. Soil strains were larger than 2 percent, and these strains were well into the inelastic region for the site soils. Comparisons of measured spectra with scaled prototype design spectra indicate that structural rocking response may have been on the order of that implied by an idealized 1/2 g design spectrum.

● **2.7-13** Saadullah, A. N., **Study of seismic activity at Mishraq sulphur mine**, *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering*, **14**, Dec. 1978, 83–98.

This paper deals with the nature of the induced earthquakes occurring at the Mishraq sulphur mine area in Iraq. Examined are large areas of land subsidence and the effects of injection of pressurized hot water into boreholes.

2.8 Earthquake Prediction

2.8-1 Murdock, J. N., **Travel time and spectrum stability in the two years preceding the Yellowstone, Wyoming, earthquake of June 30, 1975**, *Journal of Geophysical Research*, 83, *B4*, Paper 8B0060, Apr. 10, 1978, 1713–1717.

An earthquake of magnitude $M_L = 6.0$ occurred within the U.S. Geological Survey Yellowstone Park, Wyoming, seismic network on June 30, 1975. The two stations closest to the epicenter were Norris Junction (NJ)(8 km) and Madison Junction (MJ)(20 km). In the 2 years preceding the earthquake, 12 nuclear devices detonated at the Nevada Test Site and Novaya Zemlya were recorded by NJ, MJ, and other stations of the network. The proximity of the two stations to the epicenter, together with their recording of the nuclear shots, gives an exceptional opportunity to test for *P*-wave travel time and spectral changes precursive to the earthquake. The travel times at NJ and MJ were measured in relation to two stations of the Yellowstone net that were 50 to 60 km from the epicenter. To estimate the noise in the data reduction scheme, measurements similar to these were made at Hanford, Washington. In general,

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the relative arrival times at Yellowstone were as stable as those at Hanford, suggesting that no anomaly larger than fluctuations caused by data reduction (0.09 s) was associated with the impending earthquake. The *P*-wave forms of the shots recorded at NJ also were stable as a function of time, and in 1975 no anomaly was found in the *P*-wave amplitudes.

● 2.8-2 Lindh, A. G., Lockner, D. A. and Lee, W. H. K., **Velocity anomalies: an alternative explanation,** *Bulletin of the Seismological Society of America,* **68,** *3,* June 1978, 721-734.

Material velocity changes have reportedly preceded the last two magnitude 5 earthquakes along the San Andreas fault in central California. In both cases, the anomalies were based on an increase of ~0.2 sec in travel-time residuals from small regional earthquakes at one or more nearby seismic stations. A detailed reexamination of the data shows that the changes were more likely caused by differences in the depth and magnitude of the source earthquakes during the "anomalous" periods and were unrelated to any premonitory material property changes. Additional data show that travel times before the two magnitude 5 earthquakes were, in fact, stable to within a few hundredths of a sec for rays that passed within a few km of the hypocenters. It is suggested that, given the great latitude that can be exercised in the selection of data after the fact to define premonitory changes, such anomalies may not be of any significance, unless it is explicitly shown that they are not due to some other change in the sources used or signals measured.

● 2.8-3 Johnston, M. J. S. *et al.,* **Tilt near an earthquake (M_L = 4.3), Briones Hills, California,** *Bulletin of the Seismological Society of America,* **68,** *1,* Feb. 1978, 169-173.

Three years of continuous records of surface tilt preceding a moderate earthquake (M_L = 4.3) on Jan. 8, 1977, have been obtained at a point 5.5 km from the earthquake epicenter. A possible short-term precursive tilt to the southwest started Dec. 18, 1976, and reached a maximum amplitude of 2μradians relative to the tilt trend at this time. Other changes of this amplitude are evident, however, in the 3-yr record. The sense of tilt changed abruptly following the earthquake, gradually returning to the general tilt trend. A substantial postseismic tilt of 10 μradians is consistent with aseismic slip of the Hayward fault or any of several other faults local to the tiltmeter in this region. The data are insufficient to discriminate between these possibilities, and accompanying surface displacements are apparently too small to be detected in the geodetic records. Short-term accelerated tilting just prior to the seismic events, as proposed by Wood and Allen, is not apparent in these data. An observed coseismic tilt step of 0.14 μradians does not agree with that expected from current fault-failure models.

● 2.8-4 Savage, J. C. and Prescott, W. H., **Geodolite measurements near the Briones Hills, California, earthquake swarm of January 8, 1977,** *Bulletin of the Seismological Society of America,* **68,** *1,* Feb. 1978, 175-180.

Two geodetic stations, the positions of which are frequently monitored by geodetic distance-measuring techniques, were located 5 and 10 km from the epicentral area of the Briones Hills earthquake swarm (maximum magnitude M_L = 4.3) of Jan. 1977. Although a 10 μradian postearthquake tilt change was recorded at a nearby tiltmeter, no significant change in geodetic distances could be detected at a sensitivity of at least 0.5 ppm. A simple dislocation model of the main earthquake in the swarm would predict no observable change in either tilt or geodetic distance.

● 2.8-5 Weeks, J., Lockner, D. and Byerlee, J., **Change in *b*-values during movement on cut surfaces in granite,** *Bulletin of the Seismological Society of America,* **68,** *2,* Apr. 1978, 333-341.

A large granite sample with a saw cut, modeling a natural fault, was triaxially loaded at confining pressures up to 1000 bars. Fourteen violent slip events accompanied by foreshock and aftershock sequences occurred under constant strain-rate loading. From digitally recorded acoustic emission, locations and amplitudes were determined for nearly 8000 microseismic events.

Plots of log amplitude versus log frequency of microseismic events were drawn for three periods between each slip event, termed foreshock, aftershock, and background. These plots indicate that the *b*-value is lower during foreshocks then for periods between events, implying increased average amplitude of microseismic activity just before slip. These experimental results suggest that it may be possible to devise an earthquake-warning system based on changes in *b*-values in active tectonic regions. The dilatancy-diffusion model suggests that the *b*-value would decrease prior to earthquakes. In this experiment, however, the rock was dry.

2.8-6 Soga, N. *et al.,* **The effect of dilatancy on velocity anisotropy in Westerly granite,** *Journal of Geophysical Research,* **83,** *B9,* Sept. 10, 1978, 4451-4458.

Jacketed samples of Westerly granite were fractured at confining pressures up to 1 kbar and at strain rates of 2 x 10^{-5} s^{-1} and 3 x 10^{-7} s^{-1}. Compressional and horizontally and vertically polarized shear velocities were measured in orthogonal directions perpendicular to the compression axis. The strains in three orthogonal directions were monitored by strain gauges and compared with the results obtained by optical holography. At approximately 60% of the ultimate axial strain, the onset of dilatancy is noted by a decrease in the V_s and V_p velocities. As failure was

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approached, the compressional velocity across the fault decreased by nearly 40% for the low-strain-rate case versus about 22% for the high-strain-rate case. To characterize the stress-induced cracks during dilatancy, an analysis of the velocity data was carried out following the approach of Anderson et al. with the assumptions that flat spheroidal cracks were oriented perpendicular to three orthogonal directions and that the effects of oblique cracks were vectorially divided between the effects of three mutually perpendicular crack types. The comparison between the observed and the calculated velocities showed good agreement. The degree of dilatancy was determined from the differences between the strains measured perpendicularly to the compression axis and the estimated elastic strains in those directions. The aspect ratios for the flat spheroidal cracks were calculated to be 1/400 to 1/800, which are in line with those determined by Hadley.

2.8-7 Dieterich, J. H., **Preseismic fault slip and earthquake prediction,** *Journal of Geophysical Research,* **83,** *B8,* Aug. 10, 1978, 3940–3948.

It is proposed that preseismic fault creep may be the underlying process responsible for earthquake precursors. The assertion that fault creep precedes earthquakes is supported by evidence from some earthquakes and by analogy with detailed laboratory observations. Laboratory observations of stick slip reveal that at least two stages of preseismic slip are an intrinsic part of the process leading to seismic slip on preexisting faults with inhomogeneous stress or strength. During the slowly propagating first stage of creep, it is assumed that the length of the creeping fault segment is proportional to the source length of the subsequent earthquake. The data giving the well-known relationship between precursory time and earthquake magnitude are closely satisfied if the rate of propagation of the first stage of creep is independent of fault length. Long-term precursors may arise because of stress-strain variations during the first stage of fault creep. Observations of short-term precursors immediately prior to earthquakes may be related to the second short-lived state of preseismic fault slip seen in stick-slip experiments.

● 2.8-8 Raikes, S. A., **The temporal variation of teleseismic *P*-residuals for stations in southern California,** *Bulletin of the Seismological Society of America,* **68,** *3,* June 1978, 711–720.

Teleseismic P residuals have been monitored as a function of time at 13 stations in southern California during the 5-yr period 1972 to 1976. These residuals, when normalized to minimize common path and source effects and corrected for the marked azimuthal dependence of residuals in southern California, show no significant variation. This indicates that no detectable velocity changes have occurred during this time in the vicinity of the stations monitored. It is estimated that a velocity change of ~ 9% occurring over a path length of 10 km and lasting for at least 6 mo should be resolvable. Either such changes have not taken place in the region monitored, or any velocity anomalies are confined to a small depth range in the crust and are poorly sampled by teleseismic waves.

● 2.8-9 Ishida, M. and Kanamori, H., **The foreshock activity of the 1971 San Fernando earthquake, California,** *Bulletin of the Seismological Society of America,* **68,** *5,* Oct. 1978, 1265–1279.

All of the earthquakes which occurred in the epicentral area of the 1971 San Fernando earthquake during the period from 1960 to 1970 are relocated by using the master-event method. Five events from 1969 to 1970 are located within a small area around the main shock epicenter. Because this cluster of activity is clearly separated spatially from the activity in the surrounding area, these five events are considered foreshocks. The wave forms of these foreshocks, as recorded at Pasadena, are all very complex, and yet they are remarkably similar to one another. The events which occurred in the same area prior to 1969 have less complex wave forms and show a greater variation. The complexity is most likely the effect of the propagation path. A well located aftershock which occurred in the immediate vicinity of the main shock of the San Fernando earthquake had a wave form similar to that of the foreshocks; this suggests that the foreshocks also were located very close to the main shock. This complexity was probably caused by a structural heterogeneity in the fault zone near the hypocenter. The seismic rays from the foreshocks in the inferred heterogeneous zone are interpreted as being multiply reflected near the source region which yielded the complex wave form. The mechanisms of the five foreshocks are similar to each other but different from both the main shock and the aftershocks. This suggests that the foreshocks originated in a small area of stress concentration where the stress field is locally distorted from the regional field. The number of small events with S-P times between 3.8 and 6 sec recorded at Mt. Wilson each month suggests only a slight increase in activity of small earthquakes near the epicentral area during the two month period immediately before the main shock. Because these events cannot be located, the evidence is not definitive. Since the change in the wave forms is definite, the results suggest that detailed analyses of wave forms, spectra, and mechanism can provide a powerful diagnostic method for identifying a foreshock sequence.

2.8-10 Ishikawa, Y. and Miyatake, T., **An application of the Wiener's predictive filter to the records of crustal deformations and seismicity** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **31,** *1,* Mar. 1978, 73–86.

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An attempt to detect anomalies precursory to earthquakes was made by applying the Wiener's predictive filter to crustal strain, tilt, and seismicity records. The technique finds the anomalies if there are large residuals between the data observed at a certain time and their predicted values computed from past data. From records obtained at the Ikuno station, preseismic tilt changes were confirmed by this method for the 1943 Tottori earthquake. In other cases, however, the precursory phenomena are not definitive. For example, postseismic strain changes were recorded at the Kamitakara station after the 1969 central Gifu earthquake and also at the Ide station after the 1952 Yoshino earthquake.

● **2.8-11** Rikitake, T., **Biosystem behaviour as an earthquake precursor,** *Tectonophysics,* **51,** *1/2,* Nov. 20, 1978, 1-20.

An analysis of 157 existing items of data concerning abnormal animal behavior prior to an earthquake indicates apparent precursors of two kinds: moderately short range and extremely short range. These have precursory times of days and hours, respectively. The moderately short-range precursor, if it is a precursor at all, covers the time range for which very few geophysical precursors are observed, and in such a case the animal precursor supplements the geophysical one. The nature of extremely short-range animal precursors is similar to that of geophysical precursors for the same time range. Although it is hard to establish the validity of animal precursors from the present statistics, and although the reasons why animals are sensitive to usually unmeasurable stimulations preceding an earthquake is not well understood, modern reports from China, Italy, and other countries seem to evidence the existence of such precursors.

● **2.8-12** Weisbecker, L. W. *et al.,* **Earthquake prediction, uncertainty, and policies for the future: a technology assessment of earthquake prediction,** *Center for Resource and Environmental Systems Studies, Report No. 19,* Stanford Research Inst., Menlo Park, California, Jan. 1977, 315.

● **2.8-13** Sieh, K. E., **Central California foreshocks of the great 1857 earthquake,** *Bulletin of the Seismological Society of America,* **68,** *6,* Dec. 1978, 1731-1749.

Analysis of contemporary accounts indicates that several small-to-moderate central California earthquakes preceded the great 1857 earthquake by 1 to 9 hr. The earliest events apparently were felt only in the San Francisco area or the Sacramento and Sierran Foothills region. Two later and much more widely felt foreshocks were experienced within the region bounded by San Francisco, Visalia, Fort Tejon, and Santa Barbara. A comparison with felt areas and intensity distributions of modern events of known source and magnitude indicates that these later two shocks were of magnitudes greater than or equal to 5 and less than or nearly equal to 6 and probably originated at some point within an area of radius ≈60 km that includes the southeastern 100 km of the historically creeping segment of the San Andreas fault. The northwestern terminus of the 1857 rupture is probably located along this segment.

If the location of these foreshocks is indicative of the epicenter of the main event, then the several-hundred-kilometer main-event rupture propagated principally in a unilateral fashion toward the southeast. This implies that, like many great earthquakes, the 1857 rupture originated on a fault segment historically characterized by moderate activity and propagated into an historically quiet segment. There is a strong possibility that the foreshock activity represents a moderate Parkfield-Cholame sequence similar to those of 1901, 1922, 1934, and 1966. To the extent that such premonitory activity is characteristic of the failure of the 1857 segment of the fault, studies of the creeping segment of the fault may be relevant to the prediction of large earthquakes in central and southern California.

● **2.8-14** Srivastava, H. N., **Use of Kazakh nuclear explosions for testing dilatancy diffusion model of earthquake prediction,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 46, Nov. 1978, 360-368.

P-wave travel time anomalies from Kazakh explosions during the years 1965-1972 were studied and compared to the travel time tables of Bullen and Herrin. The F-ratio test was used to analyze anomalies recorded at seven stations in Himachal Pradesh, India. For these events, the temporal and spatial variations of travel time residuals were examined for long-term precursory velocity changes and the effects of local geology. The results show close agreement with the Herrin travel time tables. The F-ratio test indicated that variation between the sample means of waves recorded at different stations showed more variation than can be attributed to sampling error. Although the spatial variation of mean residuals could generally be explained on the basis of local geology, the temporal variations of such residuals from the explosions offer limited application in the testing of the dilatancy model of earthquake prediction.

● **2.8-15** Biagi, P. F. *et al.,* **Tilt variations and seismicity that preceded the strong Friuli earthquake of May 6th, 1976,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III,** 759-772. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper delineates the characteristics of the Friuli, Italy, area prior to the strong shock of May 6, 1976. The introduction discusses some of the studies begun in the 1950s of pre-seismic phenomena in the area.

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● **2.8-16** Tanaka, Y., **Reports on observations of crustal stress and crustal deformation, and their anomalous changes related to earthquakes in China,** *Stress and Strain Measurements Related to Earthquake Prediction,* 569–596. (For a full bibliographic citation, see Abstract 1.2–14.)

This paper examines observations of crustal stress and crustal deformation in the People's Republic of China and some recent results of these observations. In particular, the anomalous changes preceding the great earthquakes which occurred in 1976 (Tangshan in the Hopei Province, Yenyunan-Ninglang on the border of the Yunnan and Szechwan provinces, and Lungling in the Yunnan Province) are explained as basic data for medium-term, short-term, and imminent predictions of earthquakes.

● **2.8-17** Stuart, W. D. and Herriot, J. W., **Tilt elbows before earthquakes,** *Stress and Strain Measurements Related to Earthquake Prediction,* 521–543. (For a full bibliographic citation, see Abstract 1.2–14.)

A procedure for detecting anomalies in shallow borehole tiltmeter data prior to small and moderate earthquakes is described. The procedure involves a precise anomaly definition, a statistical method for detecting significant anomalies, and a semi-empirical model relating anomaly and earthquake parameters. Application of the procedure to two components of one tiltmeter shows that most earthquakes for which data were available were preceded by anomalies, but that approximately three-fourths of all anomalies were false alarms.

● **2.8-18** Vere-Jones, D., **Earthquake prediction-A statistician's view,** *Journal of Physics of the Earth,* **26,** 2, 1978, 129–146.

Short or medium-term risk forecasts are suggested as an alternative to presenting earthquake predictions as such. Methods for calculating such forecasts are discussed, and are illustrated with reference to Kawasumi's periodicity data. It is suggested that the primary responsibility for earthquake insurance should rest with a governmental body, which would also have responsibility for accumulating, assessing, and disseminating information on earthquake risks and methods of hazard reduction.

2.8-19 Evison, F. F., **Long-term seismic precursor to the 1968 Inangahua earthquake, New Zealand,** *New Zealand Journal of Geology and Geophysics,* **21,** *4,* 1978, 531–534.

A precursory swarm postulated for the Inangahua earthquake of May 23, 1968 (magnitude 7.1) was well defined over an area of 5000 km^2 by magnitudes as low as 2.4, the smallest located. The precursory gap was not well defined. The Westport earthquake sequence, beginning May 10, 1962, was the most intense part of the swarm and had the largest magnitudes.

● **2.8-20** Turner, R. H., **Earthquake prediction volunteers: what can the United States learn from China?,** *Mass Emergencies,* 3, *2/3,* Sept. 1978, 143–160.

● **2.8-21** Mizoue, M. *et al.,* **Earthquake prediction from microearthquake observation in the vicinity of Wakayama City, northwestern part of the Kii Peninsula, central Japan,** *Journal of Physics of the Earth,* **26,** *4,* 1978, 397–416.

A systematic variation in the mode of seismicity is presented as a process accompanying earthquakes of magnitudes ranging from 4.7 to 5.2 that occur periodically with a recurrence time of 8 to 15 years in the vicinity of Wakayama City in the northwestern part of the Kii Peninsula in central Japan. Earthquakes with magnitudes larger than 4.5 can be reasonably classified into the representative major events in this area where few shallow earthquakes are of magnitudes larger than 5.0.

By a continuous microearthquake observation undertaken in the area, a distinct aseismic zone, a so-called seismicity gap, as well as a noticeable lineament of epicentral distributions across the seismicity gap have been confirmed to exist. The seismicity gap, occupying an area of about 50 km^2, appears to be evident 2 to 3 years before a major earthquake occurrence and shows a remarkable contrast to the surrounding area characterized by earthquake swarms. The occurrence of a precursory earthquake with a magnitude as large as 4.3 at the southern border of the seismicity gap is identified as a reliable indication of a subsequent major earthquake to be expected in 6 to 7 months on a preexisting fault that crosses the seismicity gap.

● **2.8-22** Rosenblueth, E., **Earthquake prediction and engineering in China,** W. H. Smith, trans. and A. L. Collin, ed., American Iron and Steel Inst., Oakland, California [1978], 34.

This publication is a translation of *Prediccion e ingenieria sismica en China.* The Spanish version also is available.

2.9 Special Topics

2.9-1 Sobolev, G., Spetzler, H. and Salov, B., **Precursors to failure in rocks while undergoing anelastic deformations,** *Journal of Geophysical Research,* 83, *B4,* Paper 7B1083, Apr. 10, 1978, 1775–1784.

Modeling of geological processes in the laboratory is often difficult. Stress accumulation prior to an earthquake occurs over a long time and is associated with large

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anelastic deformation. In this paper, the use of pyrophyllite as a model material is discussed. Pyrophyllite was chosen because of its large anelastic deformation (several percent) before brittle failure. Samples of pyrophyllite were stressed to failure in a biaxial press. Photography through transparent pistons, optical holography, microscopy, and sound velocity measurements were used as tools to study the processes leading to brittle failure. At about 50% of ultimate failure strength, a zone of preferential deformation forms around the incipient fault, and the seismic velocities decrease perpendicular to the axis of maximum principal stress. At higher stress levels, the intense deformation zone becomes very narrow and the velocities increase again before failure. En echelon cracks form in the most narrow part of the intense deformation zone and precede the formation of a macrocrack and a stress drop. The intense deformation zone remains very narrow in front of the macrocrack. Further en echelon crack formation within the intense deformation zone appears before a further advance of the macrocrack. The above observations, especially the velocity reversal before failure, are rate- and moisture-dependent. They were clearly detectable at a strain rate of 3×10^{-8}/s but barely noticeable at 5×10^{-7}/s.

2.9-2 Bombolakis, E. C., Hepburn, J. C. and Roy, D. C., **Fault creep and stress drops in saturated silt-clay gouge,** *Journal of Geophysical Research,* 83, *B2,* Paper 7B0949, Feb. 10, 1978, 818-829.

An analysis of physicochemical processes in a saturated silt-clay gouge indicates that this type of fault zone material can account for the following phenomena: (1) the nonlinear mechanical behavior indicated by certain geophysical measurements along the San Andreas fault zone, (2) the low stress drops associated with earthquakes occurring at depths of several kilometers, and (3) the recurrence of creep-induced instabilities at shallow depths along fault zones. A rheological model is described for a gouge consisting of colloidal-size clay platelets with adsorbed water, brittle silt-size particles, and "free" pore water.

Recurrence of shallow earthquakes or accelerated creep is explained in the model by thixotropic hardening of the colloidal phase following shear deformation, i.e., by electrochemical reorientation of clay platelets from a dispersed structure to a face-to-edge type of structure during a quiescent period. The silt phase must support part of the effective mean stress for thixotropic hardening to occur at depths of several kilometers. The peak shear strength of the gouge is expressed in functional form, and it is time dependent owing to viscous-type contacts between adsorbed water layers surrounding the colloidal platelets. Its time-dependent nature may be responsible for certain nonlinear behavior noted in fault zones and for the small stress drops associated with earthquakes occurring at depths of several kilometers.

2.9-3 Martin, III, R. J., Habermann, R. E. and Wyss, M., **The effect of stress cycling and inelastic volumetric strain on remanent magnetization,** *Journal of Geophysical Research,* 83, *B7,* Paper 8B0206, July 10, 1978, 3485-3496.

The relation between remanent magnetization (natural and thermal), volumetric strain, and stress was determined for five rock types. Twenty different samples (fine-grained intrusive, gabbro, basalt, tuff, and andesite) were repeatedly cycled to 95% of their fracture stresses at confining pressures of up to 1250 bars. At the completion of the first cycle, there was always a permanent demagnetization of the rock. Subsequent stress cycles show a progressively smaller demagnetization, and the changes of remanence with loading become nearly reproducible by the fourth cycle. The onset of dilatancy produced changes in the rate of magnetization change.

For two rock types, the magnitude of the remanence increased up to the onset of dilatancy and then decreased as the stress was augmented. For these two rock types, the remanent vector first rotated toward the axis of applied stress up to the onset of dilatancy; continued loading caused a rotation away from the applied stress axis. Typically, the changes in remanent intensity were of the order of 5%, which is about 3 times smaller than the changes in the individual components parallel and perpendicular to the axis of the greatest compressive stress. In fact, it was not uncommon for one component to increase while the other decreased. As a consequence, large rotations, up to 10°, of the remanent moment were observed, and at differential stresses in excess of half the compressive strength, the remanent vector always rotated away from the axis of greatest compression. In addition, time-dependent changes in remanent magnetization of several percent accompanied time-dependent increases in crack porosity during constant stress-creep tests at high differential stresses.

● 2.9-4 Johnson, J. N. and Schmitz, D. R., **Incipient joint motion due to spherical explosion,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM4,* Proc. Paper 13936, Aug. 1978, 857-869.

The problem of incipient joint/fault motion resulting from a spherical explosion in an infinite homogeneous isotropic rock mass is analyzed. The mechanical response of intact rock is assumed to be elastic. The shear failure criterion for the joint or fault is assumed to be of the usual Mohr-Coulomb form, which results in a single scalar quantity for the definition of the stress states at which failure occurs. In some cases, unexpected orientations exist for which shear failure is inhibited, even though the fault is close to the source. In addition, a quantitative description of catastrophic shear failure on a fault or joint depends on detailed time-resolved stress histories. Simple quantitative

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models based solely on total explosive energy, for example, are incomplete.

● 2.9-5 Heaton, T. H. and Helmberger, D. V., **Predictability of strong ground motion in the Imperial Valley: modeling the *M*4.9, November 4, 1976 Brawley earthquake,** *Bulletin of the Seismological Society of America,* **68,** *1,* Feb. 1978, 31–48.

Strong-motion displacements, recorded at 33 km (IVC) and 36 km (ELC) from the Nov. 4, 1976, Brawley earthquake, are modeled using the Cagniard-de Hoop technique. The IVC record consists almost entirely of transversely polarized motion, whereas the ELC record contains an approximately equal proportion of transversely and radially polarized motion. A simplified shear-wave velocity model was determined from the compressional wave refraction studies of Biehler, Kovach, and Allen. The epicentral location and focal mechanism computed from *P*-wave first-arrival studies were used to locate and orient a double-couple point source within the layered halfspace. The far-field time function and source depth were the only parameters without good independent constraints. A triangular far-field time function with a duration of 1.5 sec and a source depth of 7 km were sufficient to model the first 25 sec of tangential ground motion. It appears that the effects of velocity structure on the propagation of long-period *SH* waves are predictable in the Imperial Valley. A study of the synthetic Fourier amplitude spectra indicates that wave propagation effects should be included in studies of source spectra and seismic wave attenuation.

● 2.9-6 Byerlee, J. *et al.*, **Structures developed in fault gouge during stable sliding and stick-slip,** *Tectonophysics,* **44,** *1-4,* Jan. 10, 1978, 161–171.

The structural changes that occurred in a thin layer of quartz gouge sheared between saw cuts in granite cylinders at pressures of 2 and 4.7 kbar were studied in detail. At low pressure the material deformed stably, but at high pressure deformation was unstable. During deformation, shear zones were developed oblique and parallel to the plane of the saw cuts. The results suggest that shearing oblique to the strike of the fault zone precedes sudden slip, which is confined to the margin between the intact rock and gouge. If this is true in the natural situation, then it may be possible, by studying the spacial distribution of the microseismic activity and creep in shear zones, to determine whether sudden slip is imminent.

● 2.9-7 Roy, A., **First motions from nonuniformly moving dislocations,** *International Journal of Solids and Structures,* **14,** *9,* 1978, 755–769.

The response of an elastic halfspace to a realistic model of faulting is considered. A dislocation is assumed to be developed along a line of finite length and then to move nonuniformly along an inclined plane (fault) surface. Analytical solutions for the surface displacement in the form of double integrals are derived by the Cagniard De-Hoop technique. The nature of wave arrivals at the surface is discussed for a decelerating and an accelerating source. First-motion responses are obtained near different wave arrivals by a limiting process.

● 2.9-8 Gilpin, B. and Lee, T.-C., **A microearthquake study in the Salton Sea geothermal area, California,** *Bulletin of the Seismological Society of America,* **68,** *2,* Apr. 1978, 441–450.

Earthquake activities in the Salton Sea geothermal field were monitored for eight weeks in 1975 with an array consisting of five portable seismographs and two USGS permanent stations. Two to three events per day ($M_L <$ 3.0), commonly occurring in clusters along with intermittent swarm activities, characterize the seismicity of the study area. Focal depths decrease toward the geothermal area where they range from 0.5 to 3.5 km, suggesting that aseismic creep occurs at higher temperature regime in the deeper part. The previously inferred Brawley fault is probably offset into two segments but connected by a leaky transform fault where the crustal spreading is reflected by normal faulting in one earthquake swarm and the crustal shearing by strike-slip faulting in another more active swarm. The activities of the latter swarm were poorly correlated with tidal gravity.

● 2.9-9 Rice, J. R., Rudnicki, J. W. and Simons, D. A., **Deformation of spherical cavities and inclusions in fluid-infiltrated elastic materials,** *International Journal of Solids and Structures,* **14,** *4,* 1978, 289–303.

The problem of a spherical cavity embedded in a linear, fluid-infiltrated, elastic porous medium and subjected to sudden quasi-static stress at the cavity boundary is solved. It is demonstrated that the deformation of the cavity is homogeneous regardless of the boundary condition imposed on the pore fluid at the cavity wall. The time dependence of the cavity strain is evaluated explicitly for the case in which the pore pressure vanishes at the cavity wall. The time dependence is shown to vary between the limits of the ordinary linear elastic response based on the short-time (undrained) and the long-time (drained) properties of the fluid-saturated solid. The results are then used to obtain a relation between the uniform stress or strain applied at infinity and the stress and strain in a highly permeable, possibly nonlinear, spherical inclusion. The application of this relationship to a study of earthquake premonitory processes, based on the deformation of a rock mass with a spherical weakened zone, is outlined. It is argued that the fluid coupling effects serve to stabilize the weakened rock against rapid fracture and give rise instead

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to a precursory period of accelerating, but initially quasi-static, straining, which ultimately leads to dynamic instability.

● **2.9-10** Sato, R., **Long-period surface velocities and accelerations due to a dislocation source model in a medium with superficial multi-layers—Part II,** *Journal of Physics of the Earth,* **26,** *1,* 1978, 17-37.

In Part I of this paper, a formulation was derived in which disturbances were obtained at the surface of a medium with superficial multi-layers caused by a dimensional fault. Part II revises this formulation by taking approximate surface wave contributions into consideration. The surface accelerations in a simple source model with a ramp-type source-time function are found to be too small, even for the long-period component discussed in this study. The possibility is discussed that large accelerations may be obtained by adopting different ramp-type source-time functions, keeping other focal factors the same as in the presently available fault model. Accelerations obtained in this way are tentative, and their absolute values cannot be discussed at this stage of seismological development. However, if surface structures at many places are clarified, and detailed behaviors of short-period components in the source time function are elucidated (especially for large earthquakes), then the present formulation may make it possible to discuss even absolute values of accelerations.

2.9-11 Holcomb, D. J., **A quantitative model of dilatancy in dry rock and its application to Westerly granite,** *Journal of Geophysical Research,* **83,** *B10,* Oct. 10, 1978, 4941-4950.

A general model of dilatancy is developed based on the behavior of individual microcracks. Macroscopic effects are described by combining the effects of individual cracks using a statistical approach. The model is developed using distribution functions for crack size, crack strength, and local stress. Hysteresis in volumetric strain and stress-strain data for partial unloading and reloading and general loading paths can be described. The model is best suited to describing rock which has been subjected to a number of loading cycles sufficient to remove the residual volumetric strain that is present in the initial cycles. This makes the rock more representative of the real earth and removes transient effects that obscure the dilatant effect. Volumetric strain data from triaxial experiments on Westerly granite are well described by the model for confining pressures from 0 to 4.11 kbar. Only one parameter is needed to describe the effect of changing the confining pressure, and this can be interpreted as an elastic effect on the crack volume. Some aspects of the crack behavior that are necessary to explain the data are incompatible with the usual sliding crack model of dilatancy. Combined with the lack of observable shear cracks, this casts serious doubts on the validity of the sliding crack model.

● **2.9-12** Sato, R., **Long-period surface velocities and accelerations due to a dislocation source model in a medium with superficial multi-layers, part I,** *Journal of Physics of the Earth,* **25,** *1,* 1977, 43-68.

Recent proliferation of large high-rise buildings makes it important to investigate long-period seismic particle velocities and accelerations besides displacements generated by the present simple dislocation source model. In this paper, expressions are derived for obtaining a displacement spectrum on the surface of a layered structure when seismic waves caused by a dimensional fault are incident at the lowest interface of the layer. The assumptions in the derivation are (1) displacements at the base of the layer are taken as twice those caused by the source; (2) only the base displacements in the distance range from $r=r_0-0.3\lambda$ to $r=r_0+0.3\lambda$ contribute to the surface displacements at $r=r_0$, λ being the wavelength considered, and the spectrum for this wavelength does not vary much in this distance range; and (3) the layer effect is taken into account by numerically evaluating an integral with respect to the angle of incidence from 0 to $\pi/2$ instead of the rigorous limits from 0 to $\pi/2+i$ x infinity (complex angle of incidence). The numerical inverse Fourier transform is carried out by using the Filon formula to obtain displacements in the time domain. Particle velocities and accelerations can be found in a similar manner.

Surface displacements, velocities, and accelerations in Tokyo, based on a hypothetical Kanto earthquake proposed by Kanamori, are calculated, assuming the surface structures beneath the city determined by Shima *et al.*. The maximum displacement, velocity, and acceleration, when the final dislocation is assumed to be 2 m, are 44 cm, 15 kine, and 15 gal, respectively. When evaluating these quantities, a Hamming frequency window is applied to the frequency range from 0 Hz to 1 Hz to avoid the truncation effect of the spectrum. The apparent predominant period of acceleration is about 4 sec or longer. It is advanced that if the epicenter of the hypothetical earthquake is located at a position about 50 km northwest of the original (Kanamori's) position, maximum displacement, velocity, and acceleration in Tokyo will be 73 cm, 18 kine, and 19 gal, respectively.

● **2.9-13** Cohen, S. C., **Numerical and laboratory simulation of fault motion and earthquake occurrence,** *NASA Technical Memorandum 78111,* Goddard Space Flight Center, U.S. National Aeronautics and Space Admin., Greenbelt, Maryland, Apr. 1978, 49.

This paper reviews the simulation of earthquake occurrence by numerical and laboratory mechanical block models. Simple linear rheologies are used in which elastic forces drive the main events and viscoelastic forces influence aftershock and creep occurrence. Friction and its dependence on velocity, stress, and displacement also play

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a key role in determining how, when, and where fault motion occurs. The discussion of the qualitative behavior of the simulators focuses on the manner in which energy is stored in the system and released by the unstable and stable sliding processes. The numerical results reveal the statistics of earthquake occurrence and emphasize the correlations among source parameters.

● 2.9-14 Caputo, M., **The distribution of the faults and the maximum magnitude of a seismic region,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III,** 709-736. (For a full bibliographic citation, see Abstract No. 1.2-7.)

This paper introduces a statistical model for earthquakes based on formulas which relate the magnitude and seismic moment of earthquakes to the size of the fault and the stress drop which generated the earthquake. The formulas show internal consistency and are confirmed by observations. For intermediate magnitudes, the formulas show the trend toward linearity seen in the magnitude statistics for all the seismic regions of the world. This linear trend changes into a curve with an increasing slope for large magnitudes.

When a catalog is available of the magnitudes and/or the seismic moments of the earthquakes in a region, the model allows the estimation of the maximum magnitude possible in the region. If the rate of the stress in the earth's crust is known, the model allows a tentative estimate of the distribution function of the faults of the region as a function of their size. The model is applied to the Friuli, Italy, region.

● 2.9-15 Wittlinger, G., Haessler, H. and Hoang Trong, P., **Contribution to the near field study of the aftershocks of the earthquakes on May 6th and September 15th 1976 in Friuli (Italy)** (in French), *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. I,** 148-164. (For a full bibliographic citation, see Abstract No. 1.2-7.)

The two 1976 destructive earthquakes in Friuli were followed by a long series of aftershocks. About 4,000 aftershocks with magnitudes between 1.5 and 5.0 were recorded by a network of telemetered stations in the epicentral zone. The spatial distribution of the foci indicates a northerly migration of the aftershocks from May to the autumn of 1976 and a concentration of aftershocks in a somewhat limited zone around the epicentral locations of the two earthquakes. The depths of the foci, between 1 and 7 km, are shallow, even for aftershocks with magnitudes above 4.0. The study of focal mechanisms shows that most of the aftershocks are due to thrust motions, except for a few strike-slip motions west of the Tagliamento River. A study of precursory phenomena for the aftershock series associated with the September 15 earthquake is conducted. The analysis of the V_p/V_s ratio shows significant variations before the main aftershocks with magnitudes greater than 4.0. This is an encouraging result for future earthquake prediction in the Friuli area.

● 2.9-16 Madden, T. R., **Electrical measurements as stress-strain monitors,** *Stress and Strain Measurements Related to Earthquake Prediction,* 301-347. (For a full bibliographic citation, see Abstract 1.2-14.)

Many of the physical property measurements made in connection with earthquake prediction studies are based on the concept that these properties are influenced by stresses or strains, especially near the failure point. Electrical properties of rocks are controlled by the fluid in the pores and cracks of the rocks. Since these are the parts of a rock most influenced by stresses, electrical measurements can be expected to be sensitive measures of changing stresses and strains. The strain changes, however, are very small, and, even though the electrical responses can amplify the effect, great sensitivity is needed in making the measurements.

This paper reviews the electrical properties of porous rock and their strain relationships and examines the possibility of making accurate electrical measurements. The factors that control the electrical conductivity of igneous and sedimentary rocks are examined. These results are used to consider the quantitative aspects of conductivity and strain relationships and to review some experimental results. Some practical limitations on making sensitive field measurements and the effect on the usefulness of electrical conductivity measurements in earthquake studies are examined. The streaming potential properties of rocks and possible surface electrical effects of changing pore pressures at depth are also reviewed. In the last section, some of the practical problems involved in making self-potential variation measurements as indicators of pore pressure variations at depth are examined.

● 2.9-17 Savy, J. B., **Determination of seismic design parameters: a stochastic approach,** *34,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Dec. 1978, 215.

In this report a model of the release of seismic energy in an earthquake is developed by assuming that a seismic event is created by the progressive rupture of small coherent patches over the entire rupture surface. The motion at the site created by the rupture of a patch is analytically found by using a dislocation model in which the fault plane is assumed to be a geometrical discontinuity across which there exists a sudden discontinuity in the displacement vector. The characteristics of the dislocation are represented by a ramp function. The solution is limited in the present case to body S-waves generated by the small patch sources. Since the motion parameter is obtained as the

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Fourier transform of the acceleration, in the complex domain, the effect of the rupture of the entire fault is obtained by superimposing the effect of all the individual patches with the proper phasing.

The model developed here is a three-dimensional model. It accounts for the directivity effects caused by the relative position of the site with regard to the fault trace, and also for the dipping of the fault plane and the nonhorizontal direction of the average propagation of the rupture. In order to generate a realistic earthquake motion, the source parameters are taken as random variables with a given probability distribution. The propagation of the rupture in the fault plane is modeled by a random-walk type process. For use in seismic risk analysis, the uncertainty in the geometry of the system is also recognized (uncertainty in the location and orientation of the fault plane). A Monte Carlo simulation technique provides a statistical description of the spectral density of the acceleration at the site for a given fault rupture. This information then is used in a nonstationary Poisson model of occurrence of earthquakes to combine the effect of all the faults in a probabilistic sense. The consistent probability power spectral density is computed as well as the root mean square and peak of acceleration response spectra. Consistent probability time histories are also computed. The report includes a guide to and a listing of the computer program PARIS.

3. Engineering Seismology

3.1 General

● 3.1-1 Anderson, J. G. and Trifunac, M. D., **Uniform risk functionals for characterization of strong earthquake ground motion,** *Bulletin of the Seismological Society of America,* **68,** *1,* Feb. 1978, 205-218.

A uniform risk functional (e.g., Fourier spectrum, response spectrum, duration, etc.) is defined so that the probability that it is exceeded by an earthquake during a selected period of time is independent of the frequency of the seismic waves. Such a functional is derived by an independent calculation at each frequency for the probability that the quantity being considered will be exceeded. Different aspects of the seismicity can control the amplitude of a uniform risk functional in different frequency ranges, and a uniform risk functional does not necessarily describe the strong shaking from any single earthquake.

To be useful for calculating uniform risk functionals, a scaling relationship must provide an independent estimate of amplitudes of the functional in several frequency bands. The scaling relationship of Trifunac for Fourier spectra satisfies this requirement and further describes the distribution of spectral amplitudes about the mean trend. In this paper, Trifunac's scaling relationship is applied to find uniform risk Fourier amplitude spectra. In finding the uniform risk spectra at a realistic site, this method is quite sensitive to the description of seismicity. Distinct models of seismicity, all consistent with the current level of knowledge of an area, can give significantly different risk estimates.

● 3.1-2 Jennings, P. C. and Helmberger, D. V., **Strong-motion seismology,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 27-53.

A summary is presented of the status of strong-motion instrumental networks and records in the United States, followed by a discussion of some recent developments in strong-motion seismology. The topics discussed include the seismological modeling of seismic sources using strong-motion records, with application to the Borrego Mountain earthquake of 1968, the Brawley earthquake of 1976, and the San Fernando earthquake of 1971; the relationship between the spectral descriptions of strong motion used in engineering and seismology; and the use of strong-motion instruments to determine local magnitude, M_L.

● 3.1-3 Kapsarov, H., **Application of macro seismic data in evaluation of seismic ground motion,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-35, 1978, 267-273.

The overturning stability of a rigid body has been analyzed to evaluate a methodology for estimation of strong ground motions. The method has been used for estimation of the lower-bound acceleration amplitude during the Mar. 4, 1977, earthquake in Bucharest.

● 3.1-4 Midorikawa, S. and Kobayashi, H., **On estimation of strong earthquake motions with regard to fault rupture,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 825-836.

A method for estimating near-field ground motions by analysis of the shape and dimension of the fault and the direction of rupture is presented. It is assumed that earthquake ground motions in the short-period range of 0.1 to 5 sec. can be regarded as superposition of the impulses from the small elements of the fault plane. The characteristics of the impulses are determined from empirical relations according to earthquake magnitude, distance from the origin,

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fault dimension, rupture mode, etc., and the response spectra of the incident waves from the seismic bedrock are calculated by superposition of these impulses. The results show good agreement with the observed seismic intensities, peak accelerations, and spectra of the near-field ground motions for the 1923 Kanto earthquake and other earthquakes.

● 3.1-5 Papastamatiou, D., **Scaling of earthquake motion,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-43, 1978, 329–335.

Earthquake motion is discussed on the basis of theoretical models. The discussion starts from a simple configuration corresponding to a seismic source in an infinite medium. The resulting Fourier amplitude spectrum shows two corner frequencies: the higher one depends on the fracture characteristics along an earthquake fault, and the lower one is a function of the size of the source and the velocity of crack propagation. The presence of a free surface and a layered earth has a more pronounced effect on the phase characteristics and a lesser effect by reshaping the amplitude spectrum. A discussion of actual cases indicates the inadequacy of available data. However, an understanding of the physics of the problem is invaluable in scaling earthquake motion and evaluating data from dynamic sources of different magnitudes.

● 3.1-6 Gurpinar, A., **An alternative to peak ground acceleration as a design parameter,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-29, 1978, 219–226.

Peak ground acceleration has been the single conventional ground motion parameter for seismic-resistant design purposes. This paper proposes a different parameter which is associated with the average level of earthquake acceleration and the duration over which this averaging is carried out. A comparison of attenuation relationships is made and the correlation between the new parameter and peak ground acceleration is investigated. Possibilities for implementing the proposal in seismic risk analyses and in calculating maximum envelopes of ground motion parameters are also pointed out.

● 3.1-7 Sagesser, R. and Baumgartner, G., **Uncertainties in the derivation of seismic design parameters from intensities,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-02, 1978, 9–16.

Earthquake design input parameters such as peak ground acceleration are still largely based on macroseismic information, particularly where observation over long periods is possible as in central Europe. As is the case for all design events having low probability, special interest must be given to reliability. From a recent case study for Switzerland, effects of uncertainties for calculated site intensities as found on risk maps and correlated accelerations, considering the results of the Friuli earthquake of May 6, 1976, are presented.

● 3.1-8 Bolt, B. A., **Fallacies in current ground motion prediction,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 617–633.

A number of methods for predicting future earthquake intensities at a site or in a region appear to contain serious fallacious arguments. The ways that fallacies in strong-motion evaluations arise are discussed and the place of observational tests is stressed. A number of general fallacies occur because of dubious assumptions about probability laws, peak acceleration, earthquake magnitude, faulting models, and the neglect of seismic surface waves. As an example, justification of important soils engineering effects calls on significant deviation from the perfect elasticity model used commonly in seismology; yet, procedures from the former studies have been transferred to the latter case with little verification. The particular case of incorrect regression of intensity I_{mm} with peak acceleration A is analyzed. A more adequate regression law is $\log A = -0.340 + 0.313\, I_{mm}$, for which the intensity is assumed to have an error distribution with variance 0.25.

● 3.1-9 Acharya, H. K., **Ground motion attenuation in the Philippines,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 379–390.

Large earthquakes occur frequently in the Philippines and cause considerable damage to life and property. In order to assess the potential for damage, it is necessary to have some knowledge of the attenuation of ground motion. Since strong-motion data are practically nonexistent in the Philippines, the only available technique for assessing attenuation is the examination of isoseismals. All earthquakes during 1949-1974 for which three or more intensity contours could be developed were used. However, because most large earthquakes occur in oceanic areas, the epicentral intensity is usually not known. The intensity at a site is expressed.

It is concluded that the ground motion attenuation in the Philippines is more severe than in the Cordilleran and the eastern section of the United States but less severe than in the California coastal range section. A comparison of the isoseismal maps of the 1906 San Francisco earthquake, the 1811-1812 New Madrid, Missouri, earthquake, and the 1976 Mindanao earthquake leads to the conclusion that

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attenuation in the southern and central regions of the Philippines is much greater than in the eastern region of the United States but slightly less than in California.

● **3.1-10** Whitman, R. V., **Effective peak acceleration,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1247–1255.

A definition of effective peak acceleration (EPA) is developed in connection with cyclic mobility (liquefaction) of sands. Available data are used to relate EPA to the magnitude of an earthquake, and hence to develop an attenuation equation for EPA as a function of magnitude and epicentral distance. An example is given illustrating the use of this new attenuation equation in risk analysis, and the extension of this approach to structures is discussed.

● **3.1-11** Murphy, J. R. and O'Brien, L. J., **Analysis of a worldwide strong motion data sample to develop an improved correlation between peak acceleration, seismic intensity and other physical parameters,** Computer Sciences Corp., Falls Church, Virginia, Sept. 1977, 103. (NTIS Accession No. PB 276 361)

A data base consisting of nearly 1600 accelerograms was assembled from the western U.S., Japan, southern Europe, and New Guinea. Statistical analysis of the accelerograms led to an equation in which maximum acceleration is a function of intensity, magnitude, and epicentral distance. A similar equation was developed in which magnitude was replaced with epicentral intensity. Further analyses of the accelerograms showed that the New Guinea and southern European records have significantly higher peak accelerations at fixed intensity levels than the western U.S. and Japanese records. Using both theoretical models and specific examples, variations in site ground motion responses were shown to be dependent on the thickness of the alluvium beneath the recording station. Predominant periods and duration, defined with spectral parameters, were not significant variables in the acceleration-intensity correlation. Reduction of the scatter in acceleration-intensity correlations may result if seismic intensity is correlated with response spectral amplitudes which show small variations in narrow period bands. Such a correlation is independent of geographic location and thus should be directly applicable to siting situations in the eastern U.S.

● **3.1-12** Brazee, R. J., **Reevaluation of Modified Mercalli Intensity Scale for earthquakes using distance as determinant,** *Technical Memorandum EDS NGSDC-4,* National Geophysical and Solar-Terrestrial Data Center, U.S. National Oceanic and Atmospheric Admin., Boulder, Colorado, Jan. 1978, 170.

An assumption is made that the attenuation of earthquake intensity either 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 1928–1974. 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.

● **3.1-13** Trifunac, M. D., **Methods for prediction of strong earthquake ground motion,** Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Jan. 1978, 2 vols., 517. (NTIS Accession Nos. PB 277 831 and PB 277 832)

This report summarizes progress to date on the characterization of strong earthquake ground motion. Statistical analysis of strong-motion accelerograms led to an equation in which Fourier spectral amplitudes of the accelerograms are functions of earthquake magnitude, epicentral distance, recording site conditions, and component direction. A similar equation was developed in which earthquake magnitude and epicentral distance were replaced with intensity. Empirical models from these equations can be used to estimate spectral shapes. Long-period spectral amplitudes on alluvial sites tend to be greater than on basement rock sites; however, on rock sites, short-period spectral amplitudes tend to be larger. Similar analyses have been carried out using absolute acceleration and pseudo-relative velocity spectra instead of Fourier amplitude spectra. A probabilistic method is recommended to estimate spectral amplitudes with resulting spectra being called "uniform risk spectra." Using this method, different geometric models of earthquake source regions can result in significantly different Fourier spectral estimates. The mathematical procedure required to generate artificial accelerograms is presented. A relationship was determined that correlates the modified Mercalli and Japanese intensity scales. Studies of the frequency dependent duration of strong shaking at a given recording station show that duration increases with increasing alluvial thickness.

● **3.1-14** Westermo, B. D. and Trifunac, M. D., **Correlations of the frequency dependent duration of strong earthquake ground motion with the magnitude, epicentral distance, and the depth of sediments at the recording site,** *CE 78-12,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Sept. 1978, 63.

In this report empirical models are presented for estimation of the duration of strong earthquake ground shaking and two related functionals for earthquake magnitude, epicentral distance, horizontal or vertical direction of motion, and the depth of sediments beneath the recording station. These models represent a refinement of the authors' similar regression analysis in terms of the rough site classification in which s = 0, 1 and 2, corresponding to alluvium, intermediate, and hard rock sites.

● 3.1-15 Goto, H. *et al.*, **Statistical analysis of earthquake ground motion with the effect of frequency-content correction** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 7, Nov. 1978, 49-56.

Regression analysis of earthquake ground motion on magnitude and epicentral distance is performed for accelerograms obtained in Japan and the United States. The Japanese accelerograms, mostly recorded by SMAC-B2, were corrected for baseline and instrumentation using a digital filter and the FFT technique. Suitable values of the lower cutoff frequency of the processing filter were determined from the reduced displacement and the velocity and from the Fourier spectra of the original records. The higher cutoff frequency was determined from the corrected accelerations and their Fourier spectra. The results are shown in tabular form.

By this method, 45 accelerograms recorded on alluvial soils in Japan have been corrected and integrated to generate velocity and displacement. They are then used for regression analysis on magnitude and distance. For purposes of comparison, 56 California Inst. of Technology accelerograms recorded on soil sites have also been used for regression analysis. They have been processed by a flat filter so that they can be directly compared with the Japanese records. The regression analysis has been performed for the peak values of acceleration, velocity and displacement, and the total power of acceleration. The results are listed and scattergrams for each case are shown along with regression curves for M = 6.5 and 7.5. The distribution of the logarithmic deviation of the data points from the regression curves is plotted.

● 3.1-16 Bell, J. M. and Hoffman, R. A., **Design earthquake motions based on geologic evidence,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 231-271. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The determination of design earthquakes, ground motions, and response spectra based on seismic risk analyses and geologic evidence is discussed in general and illustrated with results for a site in the Los Angeles harbor area. The site is underlain by approximately 300 ft of very dense sand and is located about one mile from Palos Verdes fault and about 7 miles from the Newport-Inglewood fault. The probability analyses include three seismic risk models with earthquake data records based on instrumental magnitudes, felt intensities, and geologic evidence. Emphasis is placed on the importance of historic earthquake data records based on geologic evidence. The fault risk model gives about 50% higher ground accelerations than the regional or area seismicity based on instrumental records.

● 3.1-17 Bureau, G. J., **Influence of faulting on earthquake attenuation,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 290-307. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The observation of earthquake isoseismals and isoacceleration contours suggests that faulting has a significant influence on earthquake attenuation. The fault mechanism and the extent of fault rupture influence the distribution of intensity and the resulting damage. Mathematical formulations are proposed to correlate earthquake peak acceleration and distance for different types of faulting. Data from several historical events are used as examples.

● 3.1-18 Matsumura, K. and Makino, M., **Extreme value distributions of earthquake ground motion obtained by the Poisson process (Part 1: comparison of observed distributions with analytical distributions of the largest annual ground motion)** (in Japanese), *Transactions of the Architectural Institute of Japan, 273,* Nov. 1978, 55-62.

This paper discusses the statistical distribution of the largest annual ground motion resulting from earthquakes. The extreme value distributions from 13 seismological stations operated by the Japan Meteorological Agency are obtained for the period from 1951 to 1974. Similarly, the distributions of the maximum yearly acceleration at 6 points which are part of the strong-motion seismograph network of the Port and Harbour Research Inst., Ministry of Transport, are obtained for the period from 1965 to 1974. These distributions agree well with Gumbel's extreme value distributions of the second type. Corresponding analytical distributions are obtained by the Poisson process and Gutenberg and Richter's law of magnitude. In this calculation, the b values of Gutenberg and Richter's law and the average annual rate of earthquake occurrences are estimated from the earthquake catalog for the period from 1885 to 1974. Analytical distributions of extreme values agree well with observed values.

● 3.1-19 Makino, M. and Matsumura, K., **Extreme value distributions of earthquake ground motion obtained by the Poisson process (Part 2: on the expectancy map of maximum velocity amplitudes at the bed rock throughout Japan)** (in Japanese), *Transactions of the Architectural Institute of Japan, 274,* Dec. 1978, 37-42.

A distribution map of maximum earthquake velocity amplitudes at bedrock is proposed based on the extreme value distribution of the greatest yearly velocity of earthquakes, which can be obtained by using the b value of Gutenberg and Richter's magnitude law and average annual

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earthquake occurrences as shown in this paper. When the seismic activity determined from the data for the period from 1885 to 1974 seems inadequate, the average annual rate of earthquake occurrences is modified. The primary modified areas are for the subduction zone of Japan. The relationship of the average annual rate of earthquake occurrence and the recurrence period of large earthquakes is considered.

● 3.1-20 Ishida, K., Watabe, M. and Osaki, Y., **Analysis on earthquake ground motions including vertical components (Part 1: factor analysis based on statistical method on vertical component of seismogram)** (in Japanese), *Transactions of the Architectural Institute of Japan, 273,* Nov. 1978, 63-68.

This paper discusses the results of a statistical factor analysis of the superiority of the calculated vertical components of earthquake ground motion. Two models are analyzed. Model 1 includes magnitude, epicentral distance and a ground specimen. Model 2 includes a fourth component, epicentral depth. The following results are given. (1) The order of the influence on the superiority of the vertical component (A_V) of earthquake ground motions versus horizontal components (A_H) is (a) soil specimen, (b) hypocentral distance, and (c) magnitude. None of these items alone can determine the superiority of the vertical component. (2) The epicentral depth does not sufficiently influence the ratio of maximum vertical acceleration to horizontal acceleration. (3) The calculated ratio of A_V/A_H is highly correlated with the observed ratio. (4) The fluctuation of magnitude has no significant effect upon the ratio of A_V to A_H. The softer the soil, the larger the ratio A_V/A_H becomes.

● 3.1-21 Boore, D. M. *et al.*, **Estimation of ground motion parameters,** *Geological Survey Circular 795,* U.S. Geological Survey, Arlington, Virginia, 1978, 43.

Strong-motion data from western North America for earthquakes of magnitudes greater than 5 are examined to provide the basis for estimating peak acceleration, velocity, displacement, and duration as a function of distance for three magnitude classes. A subset of the data (from the San Fernando earthquake) is used to assess the effects of structural size and of geologic site conditions on peak motions recorded at the base of structures. Small but statistically significant differences are observed in peak values of horizontal acceleration, velocity, and displacement recorded on soil at the base of small structures compared with values recorded at the base of large structures. The peak acceleration tends to be less and the peak velocity and displacement tend to be greater, on the average, at the base of large structures than at the base of small structures. In the distance range used in the regression analysis (15-100 km), the values of peak horizontal acceleration recorded at soil sites in the San Fernando earthquake are not significantly different from the values recorded at rock sites, but values of peak horizontal velocity and displacement are significantly greater at soil sites than at rock sites.

Consideration is given to the prediction of ground motions at close distances where there are insufficient recorded data points. As might be expected from the lack of data, published relations for predicting peak horizontal acceleration give widely divergent estimates at close distances (three well-known relations predict accelerations between 0.33g and slightly over 1g at a distance of 5 km from a magnitude 6.5 earthquake). After considering the physics of the faulting process, the small amount of available data close to faults and the modifying effects of surface topography, the authors believe that, at the present time, it would be difficult to accept estimates less than about 0.8g, 110 cm/s, and 40 cm, respectively, for the mean values of peak acceleration, velocity, and displacement at rock sites within 5 km of fault rupture in a magnitude 6.5 earthquake. These estimates can be expected to change as more data become available.

3.1-22 Drakopoulos, J. C., **Attenuation of intensities with distance for shallow earthquakes in the area of Greece,** *Bollettino di Geofisica,* **XX**, *78,* June 1978, 114-130.

The purpose of this paper is to systematize all available data so that they may be represented by a set of general formulas for distance (and area) as a function of the maximum intensity, I_o. A representative coefficient v of the intensity-epicentral distance relation was found using the assumption that the decay of intensity with distance is not dependent on azimuth. The best fitting to the theoretical curves was observed for v=4.8 and an average focal depth of the data used h=14 km. Adopting this depth, the authors estimated coefficients v along the large and small axes of a proposed model with theoretically elliptical isolines in order to take into account the almost constant orientation of the maximum and minimum axes in some regions. The examination of data showed that elliptically shaped isolines appeared in the regions of the Ionian Sea and in Central and SW Peloponnesus where the maximum axis has an orientation NNW-SSE, i.e., parallel to Hellenides. Taking into consideration the good quality and the large number of observational data used in this study, it is concluded that the given formulas reflect the seismic intensity field of the shallow earthquakes in Greece and surrounding areas.

3.1-23 Suhadolc, P., **Total durations and local magnitudes for small shocks in Friuli, Italy,** *Bollettino di Geofisica,* **XX**, *79,* Sept. 1978, 303-312.

Total signal durations obtained for 28 earthquakes recorded by the Osservatorio Geofisico Sperimentale network in Friuli, for which local magnitudes were provided by the Trieste station, are related to local magnitudes. The

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data are fitted using regression analysis. The obtained relation explains 88.6% of the variation in the data. The magnitudes obtained have a standard deviation as low as 0.09 magnitude units. It is found that the local magnitude, based on total signal duration, is relatively insensitive to variations in azimuth and epicentral distance. From a comparison with previous studies, it is concluded that the validity of the obtained relationship can be extrapolated to lower magnitudes.

● 3.1-24 Alsan, E., **A duration-dependent magnitude relation for Istanbul-Kandilli seismographic station** (Istanbul-Kandilli deprem istasyonu icin sureye bagli magnitud denklemi, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **6**, *21*, Apr. 1978, 34–43.

By using the signal durations of seismograms for 98 earthquakes that occurred in Western Turkey and surrounding areas from Dec. 1970 to Dec. 1977, the relation between magnitude, signal duration, and epicentral distance has been investigated for the Istanbul-Kandilli Observatory seismic station (ISK). The data involved earthquakes with magnitudes 3.4 to 5.7, epicentral distances 63 to 570 km, and focal depths less than 70 km. The least-squares fit of the data shows a good correlation for a linear relationship given in the paper. It is found that a magnitude-duration relationship will increase the number of magnitude determinations, especially for local earthquakes, in comparison with the determinations obtained by using magnitude-amplitude relationships.

● 3.1-25 Hattori, S., **Factor analysis on the vertical-horizontal ratio of maximum earthquake motions**, *Bulletin of the International Institute of Seismology and Earthquake Engineering*, **16**, 1978, 69–87.

A factor analysis was conducted of the vertical-horizontal ratio of the maximum earthquake motions using the seismic data obtained by the strong-motion seismograph of the Japan Meteorological Agency. The results are as follows: (1) The factors which are highly correlated with the vertical-horizontal ratio are the magnitude, the epicentral distance, the period of maximum amplitudes and the epicentral direction. (2) Regional characteristics of the order of importance of the factors are recognized. From the characteristics, Japan and its vicinity may be divided into five regions. (3) The mean values of the solutions for each category in each factor were obtained for the above regions. Using the mean values, the vertical-horizontal ratios at arbitrary points for fixed earthquakes can be presumed. (4) It is possible to estimate the vertical maximum earthquake motions on the ground from the vertical-horizontal ratio, the expectations of the horizontal maximum earthquake motion, and the ground characteristics.

● 3.1-26 Street, R. L., **A note on the horizontal to vertical Lg wave-amplitude ratio in eastern United States**, *Earthquake Notes*, **49**, *2*, Apr.-June 1978, 15–20.

In the structural design process for structures located in the eastern United States, seismologists and engineers frequently need to estimate the maximum horizontal ground motion from a given m_{bLg} vertical-component magnitude and an epicentral distance. In addition, the seismologist occasionally needs to estimate an earthquake's m_{bLg} magnitude from horizontal amplitude data. This paper reports on a sample of horizontal and vertical ground motion observations and suggests how the two sets of data are related.

3.1-27 Kobayashi, H., **On some problem of engineering seismology**, *Bollettino di Geofisica*, XX, *78*, June 1978, 131–144.

This paper discusses two-dimensional earthquake ground motions and evaluates the intensity of ground motions for use in structural design. In the latter case, response analyses for several types of structures were conducted and compared with such ground motion parameters as peak acceleration, maximum particle velocity, and maximum displacement.

3.2 Strong Motion Records, Interpretation, Spectra

● 3.2-1 McGuire, R. K., **Seismic ground motion parameter relations**, *Journal of the Geotechnical Engineering Division, ASCE*, **104**, *GT4*, Proc. Paper 13661, Apr. 1978, 481–490.

The relationships among spectral velocities for 0.5 Hz and 1.0 Hz frequencies, peak ground acceleration, and peak ground velocity of earthquake-induced ground motion are investigated using the horizontal components of motion from 70 California strong-motion records, accounting for event size, source-to-site distance, and geologic conditions at the recording site. These strong-motion records indicate that the estimation of intermediate-frequency spectral response using ground acceleration and typical design spectra is unconservative for a large, distant event (magnitude 8+, 120 km epicentral distance) by a factor of about 2 to 6, depending on the site geology. Ground velocity can be used to estimate intermediate frequency spectral response; however, expected spectral response will exceed these estimates during the motion from large, distant events by a factor of about 1.4 to 2.5. Because of the large variabilities associated with strong-motion data, these results are tentative.

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● 3.2-2 Morrison, P. *et al.*, **Earthquake recordings on or near dams**, California Inst. of Technology, Pasadena, 1977, 125.

The Panel on Instrumental Recordings at Dams, appointed by the Committee on Earthquakes of the United States Committee on Large Dams, has collected copies of significant earthquake strong-motion accelerograms recorded on or near dams. The locations of the strong-motion instruments are shown and copies of the significant records are included. Site geology, the dams themselves, and the strong-motion instrumentation employed are described.

Nine recordings from Los Angeles-area dams during the San Fernando earthquake of Feb. 9, 1971 and the Oroville Dam recordings of Aug. 1, 1975 are examined. Also examined are three recordings from dams outside the United States: the Koyna Dam, India, Dec. 11, 1967; the Hsinfengkiang Dam, Peoples Republic of China, a magnitude 4.5 aftershock on Dec. 18, 1972 (main shock, M = 6.1, Mar. 19, 1972); and the El Infiernillo Dam, Mexico, July 3, 1973. Two tables, arranged in chronological order of earthquake occurrence, describe the instrument locations at the dams and the availability of plots of acceleration, velocity, displacement, the response spectrum (log-log plot), and the velocity spectrum. Also included are the range of peak values of acceleration recorded by the instruments and references where detailed descriptions of the records and their analyses may be found.

● 3.2-3 Tso, W. K. and Hsu, T.-I., **Torsional spectrum for earthquake motions**, *Earthquake Engineering and Structural Dynamics*, **6**, *4*, July-Aug. 1978, 375–382.

A method of computing the torsional spectra resulting from the rotational component of seismic ground motions is presented. The rotational component is estimated from the earthquake acceleration records. In contrast to previous studies, no differentiation of acceleration records is made in this method. The torsional spectrum of the 1940 El Centro earthquake is computed and compared with previous results. An average and a mean plus one standard deviation torsional spectrum is presented for design purposes. These spectra are based on four historical records (1934 El Centro, 1940 El Centro, 1949 Olympia, and 1952 Taft) normalized to the 1940 El Centro intensity.

● 3.2-4 Bogdanov, V. I. *et al.*, **On seismometry of residual deformation of soil and structures**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-37, 1978, 283–288.

The proposed method of deconvolution of a seismogram permits the determination not only of the oscillation movement, but also the residual displacement. Examples are described of application of the method to shaking table movement and to oscillations at epicenters of earthquakes or explosions. It is shown that the complete (oscillation + residual) movement can be reconstructed from galvanometric records with an accuracy of about 10-20%. The attenuation law of residual displacement for explosions is given.

● 3.2-5 Cloud, W. K., **Modification of seismic waves by a building**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-38, 1978, 289–295.

Modification of seismic waves by a building has been documented at a site in Los Angeles, California. Accelerographs in the 12-story Hollywood Storage building and 112 feet west on a lot recorded both the 1952 Kern County earthquake (M = 7.7), and the 1971 San Fernando earthquake (M = 6.5). Analysis of the accelerograms in terms of 5% damped absolute acceleration response spectra shows that the building acted as a frequency-dependent filter. The filtering was especially noticeable on spectra from the San Fernando earthquake records, where basement spectra averaged 50% less than the lot spectra in the frequency range 4-25 Hz.

● 3.2-6 Basili, M. and Brady, G., **Low frequency filtering and the selection of limits for accelerogram corrections**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-33, 1978, 251–258.

For the processing of a wide variety of strong-motion accelerograms, some changes have been made to the computer processing routines developed by the California Inst. of Technology and subsequently used by the Seismic Engineering Branch of the U.S. Geological Survey and many other investigators. These changes are mostly related to the use of Ormsby's digital filter for the baseline correction of the records. Relationships between the time window of the Ormsby filter, the number of filter weights, and the width of the roll-off ramp have been established to achieve a more suitable use of these parameters. A new scheme has been developed for the selection of the cut-off and roll-off frequencies.

● 3.2-7 Sadigh, K., Youngs, R. R. and Power, M. S., **A study of attenuation of peak horizontal accelerations for moderately strong earthquakes**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-32, 1978, 243–250.

Relationships were developed for attenuation of peak horizontal accelerations using recordings obtained on deep soil sites during moderately strong ($M \sim 6\ 1/2$) earthquakes. Attenuation relationships were derived on the basis of: (1) both horizontal components, (2) stronger components only, (3) weaker components only, (4) spectrally maximized records, and (5) spectrally maximized records

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low-pass filtered to 2, 5, and 10 Hz. Stronger components were found to attenuate with distance at a somewhat faster rate than the weaker components. Spectrally maximized records show slightly lower scatter in data compared to both horizontal components. The filtered records show faster attenuation rates the higher the frequencies retained in the accelerograms.

● 3.2-8 Iwasaki, T. *et al.*, **Statistical analysis of strong-motion acceleration records obtained in Japan,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 705–716.

This paper presents the results of a multiple regression analysis of 301 strong-motion acceleration records, and also shows the results of an analysis of average response accelerations obtained from 277 horizontal component acceleration records. Based on these analyses, empirical formulas for statistically estimating maximum horizontal acceleration, duration of motion, and numbers of zero-crossings in terms of earthquake magnitude, epicentral distance, and subsoil conditions, are proposed. Frequency characteristics of horizontal motions and ratios of vertical to horizontal accelerations are evaluated. Average response spectrum curves for a linear single degree-of-freedom system are proposed in terms of earthquake magnitude, epicentral distance, and subsoil conditions.

● 3.2-9 Tosic, M. B., **Component maxima and resultants of strong motion parameters,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-31, 1978, 235–242.

Because of the spatial nature of ground motion and the orientation of recording instruments, the strongest record of an event at a site is not necessarily the largest that could have been obtained. Combining component accelerograms of an event will give effects exceeding those provided by a single record. Using results from a great number of processed records, empirical correlations were derived among strong-motion parameters such as maximum ground acceleration, velocity, displacement, and energy input. From an analysis of horizontal and total accelerations and velocities, criteria were defined for assessing the largest seismic input in terms of the component maxima.

● 3.2-10 Petrovski, D. and Naumovski, N., **Analysis of strong motion records of recent earthquakes obtained in Yugoslavia,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-16, 1978, 115–121.

The Inst. of Earthquake Engineering and Engineering Seismology in Skopje has developed a procedure for strong-motion data processing to obtain more exact information. Some important characteristics of this procedure are discussed in this study. Using this procedure, several recent earthquake records obtained in Yugoslavia have been analyzed. In addition, comparison is made with other ground motion data during strong earthquakes. The purpose is to emphasize the importance of the frequency composition of the ground motion upon structural behavior.

● 3.2-11 Crempien, J. and Saragoni, G. R., **Influence of the duration of earthquake ground motion in average response spectra,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-20, 1978, 143–150.

A study of the influence of the duration of the strong motion part of accelerograms on average response spectra is conducted, considering accelerograms as nonstationary processes obtained from modulation of stationary Gaussian processes by deterministic chi-square functions. This simple model provides most of the meaningful characteristics of accelerograms for seismic design, and it defines a strong-motion region and the duration of motion. Approximated expressions for average response spectra are established in terms of the mean square amplitude, frequency content, and duration of the strong-motion part of accelerograms. It is concluded that the duration of strong motion is an important parameter in the response of linear structures as are the amplitude and frequency content of accelerograms.

● 3.2-12 Swanger, H. J. and Boore, D. M., **Importance of surface waves in strong ground motion in the period range of 1 to 10 seconds,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1447–1457.

Analysis of the El Centro recordings of the 1968 Borrego Mountain, California, earthquake suggests that nearly all of the first 40 sec of the largest motion in the 2 to 10 sec period range can be described quite well by surface waves. It is this period range that is of particular concern in the design of offshore structures. The experience with the Borrego Mountain earthquake recordings suggests that surface waves are an important component of the ground motion at the periods which interest engineers. It also shows that existing techniques for computing surface wave characteristics can be applied to the prediction of ground motions in the offshore geologic environment where data are not currently available. Synthesis of surface wave motion in crustal models similar to those expected in a continental shelf suggests that the long-period characteristics of motion are controlled not only by near-surface soil characteristics but also by the characteristics of the bedrock below. Differences in the bedrock structure with depth may result in differences in the ground response of a factor of four or more. Gradients in seismic velocity with

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depth can amplify a wide period range. Sharp contrasts at depths as great as a few km can cause strong resonances in the surface waves at particular periods. These results suggest that for long-period design problems one cannot assume that all rock structures respond in the same manner. Site classification may be more meaningful in terms of regional geology or depth to basement rather than surface lithology.

● 3.2-13 Seekins, L. C. and Hanks, T. C., **Strong-motion accelerograms of the Oroville aftershocks and peak acceleration data**, *Bulletin of the Seismological Society of America*, 68, 3, June 1978, 677-689.

In the 90 days following the Oroville, California, earthquake (Aug. 1, 1975; $M_L = 5.7$), 313 positively identified strong-motion accelerograms were obtained for 86 different aftershocks. This set of records covers a wide range of magnitude, focal depth, and site conditions (Holocene alluvium to Mesozoic crystalline basement). Most of these records were written at hypocentral distances $R \leq 15$ km, a distance range for which relatively few strong-motion accelerograms had previously been available. Equally significant is the completeness of coverage (seven or more positively identified records) available for each of 12 well-recorded aftershocks. One hundred and sixty-five peak acceleration values at $6.7 \leq R \leq 15$ km for 33 aftershocks ($3.0 \leq M_L \leq 4.9$) are the basis of an investigation of the dependence of peak acceleration on magnitude at $R \cong 10$ km. These observations are supplemented with one datum for the main shock, six observations for two $M_L \geq 5$ aftershocks, and 61 null observations.

Peak accelerations at sites on bedrock or minor sedimentary thicknesses are consistently higher than those at sites on several hundred meters or more of sedimentary rocks. Mean values for both site classes of data increase fairly rapidly with magnitude for $3 \leq M_L < 5$, but the little available data for $M_L > 5$ suggest this magnitude dependence abruptly terminates at $M_L \cong 5$. The magnitude dependence of the sedimentary-site data is apparently stronger than for the bedrock-site data. Much if not all of the apparent magnitude dependence of these data can be attributed to properties of the path and not the source, consistent with the hypothesis that the amplitude of the peak acceleration phase, as it leaves the source region, does not depend on source strength, although the predominant frequency of this phase increases as the duration and magnitude of the earthquake decreases.

● 3.2-14 Bycroft, G. N., **The effect of soil-structure interaction on seismometer readings**, *Bulletin of the Seismological Society of America*, 68, 3, June 1978, 823-843.

Rocking and vertical and horizontal translations of typical "free-field" seismometer installations lead to magnification of the ground motion record. This magnification can be significant for the higher frequency components if the terrain has a relatively low shear-wave velocity. Seismometers placed on foundations which cover a significant part of a wavelength of a horizontally incident wave experience an attenuated ground motion. A method for correcting the seismograms for these effects is given. Compliance functions for a rigid sphere in a full elastic space are derived and are used to show that, in practical cases, down-hole seismometer installations are not significantly affected by interaction. These compliance functions should be useful in examining the soil-structure interaction of structures erected on bulbous piles. They may also be used as the basis of a method for determining elastic constants of ground at depth, in situ, and at different frequencies.

● 3.2-15 McGuire, R. K., **A simple model for estimating Fourier amplitude spectra of horizontal ground acceleration**, *Bulletin of the Seismological Society of America*, 68, 3, June 1978, 803-822.

A simple model for estimating Fourier amplitude spectra (*FS*) is calibrated, using the horizontal components of 70 strong-motion records from California, chosen so that the results are not biased by the effects of one earthquake nor by the effects of a single site. An exponential dependence of *FS* on magnitude *M*, a geometric dependence of *FS* on source-to-site distance *R*, and a soil amplification term Y_s are included in the model. The trends indicate that: (1) larger magnitudes imply relatively more energy content at long periods; (2) source-to-site distance has an important effect on spectral shape, because high-frequency spectral amplitudes attenuate faster with distance than do long period spectral amplitudes; and (3) alluvium site conditions amplify long-period amplitudes over those recorded at rock sites by a factor of about 1.6, but decrease short-period amplitudes.

Values of *FS* calculated from strong-motion records are lognormally distributed about the values predicted from this model. The accuracy of the model, as measured by the dispersion in observed values, is as good as the accuracy implied by the model proposed by Trifunac. Moreover, the model used in this study reflects a realistic change in frequency content with distance, which the Trifunac model does not. Hence, extrapolation of this model to estimate spectral amplitudes for large magnitudes at close distances is more reliable than is extrapolation of the Trifunac model. The model estimates the horizontal spectral amplitudes of the records obtained at Pacoima Dam in 1971 and El Centro in 1940; however, these records were not used in the calibration procedure, and the estimation of their spectral amplitudes constitutes an independent prediction.

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Investigation of possible nonlinear dependence of ln FS on M, using a form similar to that proposed by Trifunac, reveals that the M^2 term does not appreciably improve the accuracy of the model, nor does it greatly change values of predicted spectra for the magnitude range of available data (5 to 7.7). The significance of the M^2 term depends solely on records obtained during the 1952 Kern County earthquake; thus, use of models of this type, calibrated with available California strong-motion records, implies that the Kern County records are typical of a magnitude 7.7 shock.

● 3.2-16 Chen, P. C. and Chen, J. H., **Generation of floor response spectra directly from free-field design spectra,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1169–1186.

An approach which utilizes recent developments in the theories of probabilistic structural dynamics and random processes is studied. The approach is used for generating floor response spectra directly from free-field design spectra. Earthquakes are considered as stochastic processes, and free-field power spectra from free-field design spectra are computed using the extreme value theorem of stochastic processes. The power spectra of the response of linear systems are then determined using random vibration theory and the method of complex response. The floor response spectra of the structures are obtained by using the response power spectra of a linear system developed by studying the relationship between power and response spectra.

Numerical examples are provided to illustrate the application of the direct method for generating floor response spectra of a nuclear facility. The Nuclear Regulatory Commission (NRC) free-field design spectra are used as input excitations. The generated floor response spectra are compared with spectra obtained by the time-history method, using six distinct NRC spectrum-compatible synthetic earthquakes. The approach is shown to be a reliable method for determining seismic forces for equipment design.

● 3.2-17 Chandrasekaran, A. R. and Paul, D. K., **Velocity response spectra for sites on rock or soil,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1157–1167.

For the seismic-resistant design of structures, information on ground motion in the form of response spectra is used almost invariably since it conveniently represents the combined influence of the amplitude of ground acceleration, the frequency content, and to some extent the duration of ground shaking on different structures. Several investigators have studied the shape of response spectra for different site conditions and different confidence levels using different methods of normalization. In this study, a new criterion for selecting the normalizing parameter, based on least standard deviation, is suggested for velocity response spectra. Spectrum shapes corresponding to various confidence levels are proposed for rock and alluvial sites.

● 3.2-18 Hisada, T. *et al.*, **Design spectra for stiff structures on rock,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1187–1198.

Standard response spectra are proposed for stiff structures, such as nuclear power facilities, to be constructed on rock sites. The proposal is based principally on accumulated information on the peak accelerations of ground motions in near-fields. It is also based on analyses of approximately 50 accelerograms, obtained on rock outcroppings, actuated by considerably strong earthquakes with intermediate or distant epicenters. The dependence of significant response spectra parameters on magnitudes and epicentral distances is closely examined to obtain values required to construct standard response spectra. Considerable judgment is exercised for the refinement of the final shapes of the response spectra. The proposed response spectrum is defined for each of 3x3 matrices in terms of magnitudes 6, 7, and 8, and near, intermediate, and far epicentral distances. The definitions of near, intermediate, and distant earthquakes are, in turn, dependent on the magnitude of each earthquake.

● 3.2-19 Hadjian, A. H., **On the correlation of the components of strong ground motion,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1199–1210.

Nine earthquakes are studied in an attempt to identify the correlation between any two components of ground motion. Since accelerographs generally are oriented arbitrarily (in a seismological sense), the recorded motions are only one set out of a multitude of other possibilities. Thus, any statistical study of ground motion also should consider these other possibilities. The approach used here shows that the three components of ground motion are correlated in a special way, rather than being statistically independent. The correlation of the two horizontal components can be made either zero or a maximum for some orientations of the accelerograph. In fact, these orientations are separated by 45°. For some orientations of the accelerograph, the vertical component of motion is usually maximally correlated with one horizontal component, and zero is correlated with the other. Under these circumstances, it seems

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that it would be contradicting nature to insist that the three components of ground motion are statistically independent.

● 3.2-20 Benjamin, J. R., Webster, F. A. and Kircher, C., **The uncertainty in seismic loading and response criteria,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1369–1381.

This paper presents the first results of statistical analyses of earthquake response spectra based on the assumption that each earthquake is a unique event. The spectra are analyzed using multiple-nonlinear regression with a mean value function that is the sum of two exponential-type terms. Two sets of data are analyzed which show the uncertainty in seismic loading and associated response spectra. Response spectra corresponding to 13 earthquakes recorded at one instrumental site (El Centro Station No. 117) are analyzed and compared to the response spectra corresponding to the simultaneous recordings of a single earthquake (the June 27, 1966, Parkfield event) at seven instrumental sites. The first of these analyses produces results upon which site-specific response spectra criteria could be developed. The latter analysis illustrates the type and level of uncertainties in data for one earthquake.

● 3.2-21 Werner, S. D. and Ts'ao, H. S., **A study of vertical ground response spectrum shapes,** Agbabian Assoc., El Segundo, California, Aug. 1977, 58.

The effect of different normalizing procedures on the shape of response spectra for vertical earthquake ground motion was investigated. Vertical free-field earthquake ground motion records processed at the California Inst. of Technology were used for the study. Spectral shape comparisons were made for composite spectra derived from spectra normalized to peak ground acceleration, peak ground velocity, and peak ground displacement. Spectral shapes were also derived by a three-segment method and from natural (i.e., not normalized) spectra. Effects of local geology and soil conditions on response spectra shapes were also considered. Vertical spectra were developed for five different damping ratios using the three-segment method.

The results indicate that spectra developed from the statistical analysis of natural ground motion data have two advantages over spectra developed from the statistical analysis of normalized spectra shapes, namely (1) the spectra will not be distorted by the normalizing process; and (2) the probability of exceeding by the composite spectra can be well defined rather than approximated. Comparisons of composite spectra developed from both natural data and from normalized spectra with Regulatory Guide 1.60 procedures indicate that these procedures lead to overly conservative vertical ground response spectra. Comparisons of spectra for different site conditions indicate that the method selected for normalizing the data has an important bearing on the extent to which local site effects appear to influence the spectrum shape.

● 3.2-22 Chang, F. K. and Krinitzsky, E. L., **Duration, spectral content, and predominant period of strong motion earthquake records from western United States,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 8,* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Dec. 1977, 82.

The purposes of this investigation were to assess the duration and spectral content of strong-earthquake accelerograms and, indirectly, to consider their applicability in earthquake design. Correlations of duration with modified Mercalli intensity for the near and far fields and for Richter magnitude were obtained. Difference in durations for soil and rock sites was determined. A set of relationships between the duration and distance for soil and rock sites was established from records of the San Fernando earthquake of Feb. 9, 1971 (magnitude of 6.5). Values for other magnitudes were extrapolated. Duration is defined as the time interval between the first and last peaks of acceleration equal to or greater than 0.05 g.

The spectral content in the range of 0.1-10 Hz for strong-motion records in western United States, for acceleration levels equal to or greater than 0.05 g, was processed with the modified Nigam and Jennings response spectra computer programs. The corrected accelerograms on the digital magnetic tapes of NIS 130, 131, and 132 provided by the California Inst. of Technology were the input data for this study. The critical damping ratios of 5.0%, 7.5%, and 10.0% were assigned to the soil (soft, alluvial), intermediate (firm sediments), and rock (hard) sites, respectively. The relative response spectral amplitudes of acceleration, velocity, and displacement were reduced to the ground surface by dividing the relative response spectral amplitude by the dynamic amplification factor of 1/2h, where h is the critical damping ratio. The frequency-amplitude spectra were then plotted as a function of magnitude, epicentral distance, and site conditions.

The characteristics of duration are as follows: (2) duration is greater in the near field than in the far field and greater in alluvium than in rock, with the duration ratio of alluvium to rock approximately 2 to 1; (2) duration increases with magnitude and intensity, as expected; and (3) the maximum duration at a source in rock for magnitude 8.5 was extrapolated to be about 43 sec. The duration is twice as long when there is magnification by alluvium or soil.

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Frequency content and spectral shape have the following characteristics: (1) the predominant frequencies of the strong-motion earthquakes for the magnitude of 5.3-7.7 are in the range of 0.1-6.67 Hz; (2) the maximum acceleration, velocity, and displacement levels are within the ranges of 1.5-5.0, 0.5-1.5, and 0.1-0.5 Hz; (3) the predominant period of the acceleration spectra does not increase with distance within the range of 0-90 km, but the predominant period of displacement does; (4) the spectral mode shape depends on the source spectrum function (magnitude), distance, and local geological conditions; (5) generally, the average or upper-bound peak amplitudes have a uniform envelope, but the possible maximum acceleration is found to be about 0.5 g near surface faulting for the discrete frequency range of 4-5 Hz; and (6) the summation of the maximum amplitude level of the predominant frequencies equals approximately the total amplitude of the ground motion in time history if the selected damping ratio corresponds to the geological condition of the recording site. It is assumed that the amplitudes of all discrete frequencies on the envelope are in phase.

● 3.2-23 Trifunac, M. D., **Response spectra of earthquake ground motion,** *Journal of the Engineering Mechanics Division, ASCE,* 104, *EM5,* Proc. Paper 14051, Oct. 1978, 1081–1097.

In this paper a method is presented for direct scaling of pseudo-relative velocity spectra (PSV) in terms of: (1) earthquake magnitude M and epicentral distance R, or (2) modified Mercalli intensity (MMI) at a site. These models also depend directly on the geologic site conditions and are presented for horizontal and vertical ground motions. This scaling is realized by means of "coefficient" functions which are determined through regression analysis of computed PSV spectra from recorded accelerograms. One of the principal advantages of the proposed method is that the ambiguities associated with the scaling of the fixed-shape spectra by means of peak amplitudes of ground motion are now completely eliminated. The 91 direct regressions of horizontal and vertical spectra, at 91 periods, and smoothed over all, lead to more complete and reliable sampling of the frequency-dependent characteristics of strong ground motion than the correlations of peak amplitudes alone.

● 3.2-24 Glover, D., **Catalog of seismogram archives,** *Key to Geophysical Records Documentation No. 9,* U.S. National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado, May 1977, 55.

The National Geophysical and Solar-Terrestrial Data Center (NGSDC) is one of the six major facilities of the National Oceanic and Atmospheric Administration's (NOAA) Environmental Data Service. NGSDC's seismological services include preparing local and regional seismic histories; answering public inquiries on all aspects of historical earthquakes; publishing historical compilations and annual earthquake summaries; and making available copies of seismograms, strong-motion earthquake records, computer listings and plots of earthquake locations, and other data in a variety of formats.

The purpose of the catalog is to describe seismograms available from NGSDC and to permit a quick and comprehensive review of seismograms currently on hand. A map of the stations presently furnishing seismograms to NGSDC is presented. The original paper seismograms from stations operated by NOAA and its predecessor organizations prior to 1962 are held in the National Archives and the Federal Records Center. They can be obtained upon request in formats similar to the more recent data.

● 3.2-25 **Accelerograms of strong-motion earthquake, 12 June 1978,** Building Research Inst., Japan Ministry of Construction, Tokyo, 1978, 55.

● 3.2-26 Chang, F. K., **Catalogue of strong motion earthquake records, Volume I, western United States, 1933–1971,** *Misc. Paper S-73-1, State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 9,* Soil and Pavements Lab., U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Apr. 1978, 53.

This paper is a working catalog which facilitates the selection of strong-motion earthquake records for design purposes. The records are those processed by the California Inst. of Technology from the western United States during the period 1933–1971. They are presented graphically in terms of magnitude, type of fault, focal depth, site classification, peak acceleration, velocity, displacement, duration, and distance from epicenter.

● 3.2-27 Iai, S., Kurata, E. and Tsuchida, H., **Digitization and corrections of strong-motion accelerograms** (in Japanese), *Technical Note 286,* Japan Port and Harbour Research Inst. [Yokosuka], Mar. 1978, 56.

In the strong-motion earthquake network in Japanese port areas, acceleration time histories are recorded with the SMAC-B2 and the ERS accelerographs. The records of maximum acceleration exceeding 50 gals are included in digitized form in the Annual Report on Strong-Motion Earthquake Records in Japanese Ports. Recently, the digitized records have been widely used and records of higher accuracy are in demand. It also has become necessary, in both research and practice, to integrate the acceleration time histories for obtaining time histories of velocity and displacement. To meet these demands, the procedure for digitizing accelerograms was examined and improved. The errors in the digitized records were studied quantitatively. Procedures for baseline and instrument corrections, and integration of acceleration time histories, were developed.

It is expected that the procedures for digitization, correction, and integration will be used to process data for the annual reports since 1976.

● 3.2-28 Ljatkher, V. M. and Frolova, N. I., **Statistical forecast of the seismic loads,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-41, 1978, 311–319.

● 3.2-29 Petrovski, J. *et al.*, **The Thessaloniki earthquake of June 20, 1978, Vol. III: Response spectra of strong motion records,** *63,* Inst. of Earthquake Engineering and Engineering Seismology, Univ. of Skopje, Yugoslavia, Sept. 1978, 30.

● 3.2-30 Hoshiya, M., **Three dimensional analysis of San Fernando earthquake motions,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. I, Paper 1-22, 1978, 159–166.

The theory of multidimensional nonstationary random processes is summarized. Based on a nonstationary cross-spectral matrix, the theory examines principal axes and introduces a simulation method. The characteristics of the acceleration records of the 1971 San Fernando earthquake are investigated, and the simulation is carried out by the above theory. The ground motion characteristics, the wave content, and the direction of wave propagation are made clear by the principal axis concept.

● 3.2-31 Anderson, J. G., **Program EQRISK: a computer program for finding uniform risk spectra of strong earthquake ground motion,** *CE 78-11,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Aug. 1978, 54.

This report lists the computer program EQRISK for computing uniform risk spectra (URS) of strong ground motion. As described by Anderson and Trifunac, URS are found by computing the probability functions independently in several frequency bands. From these functions a complete spectrum may be found for which the probability that it will be exceeded in the selected time interval is independent of frequency. The computer listing contains a thorough description of the input parameters. The theory behind some of the options is explained, and references which give further details are described.

● 3.2-32 Isoyama, R., Yoshida, T. and Katayama, T., **Quantitative analysis of near-field earthquake ground motions** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 31, Nov. 1978, 241–248.

Characteristics of near-field earthquake ground motions are analyzed using records obtained primarily during the Matsushiro earthquake swarm. The validity of the empirical formulas recently proposed by Iwasaki et al. is examined using near-field data of the maximum acceleration, the duration of strong motion, and the number of zero-crossings during the strong motion. Also investigated is the frequency content of near-field accelerograms. Spectral moments and parameters are used to characterize the shape of the power spectrum. To compare the frequency content of near-field earthquake motions with those of medium- to far-field earthquake motions, 48 accelerograms obtained from a SMAC accelerograph are analyzed by using spectral parameters. Results are presented and discussed.

● 3.2-33 Katukura, H., Watanabe, T. and Izumi, M., **A study on the phase properties of seismic waves,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 27, Nov. 1978, 209–216.

The phase properties of the Fourier integral of a recorded seismic wave and theoretical waves calculated from fault models in the frequency domain are analyzed using the quantity of group delay, which is the derivative of phase lag with respect to angle frequency. In the calculation of group delay, the phase lag is composed of a monotonously increasing function of angle frequency from the real and imaginary part of the Fourier wave integral. It becomes clear, through an analysis of the phase characteristics of the waves with the group delay, that the variation of the group delay has a comparatively close relationship to the nonstationary properties of the amplitude of the original waves.

● 3.2-34 Kamiyama, M., **Wave interpretation of strong earthquake ground motions,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 28, Nov. 1978, 217–224.

A multiple filter technique is applied to strong earthquake ground motions in order to obtain nonstationary spectral characteristics. The analysis of several typical SMAC records from Japan indicates that a significant portion of strong earthquake ground motion has a certain regularity in its nonstationary spectral characteristics. The regularity can be explained by the dispersion characteristics of surface waves. A procedure for the simulation of surface waves propagating through a heterogeneous ground is carried out to verify the adequacy of the explanation. It is concluded that the principal motions of the SMAC records consist of surface waves.

● 3.2-35 Iai, S. and Kurata, E., **Integration of strong-motion accelerograms,** *Proceedings of the Fifth Japan*

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Earthquake Engineering Symposium-1978, Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 29, Nov. 1978, 225–232.

Errors in digitized accelerograms are examined; and, based on the examination, two filters for integrating the strong-motion accelerograms of the Port and Harbour Research Inst. (Japan) are presented.

● 3.2-36 Ohsaki, Y. *et al.,* **A study on phase characteristics of earthquake motions and its applications** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 26, Nov. 1978, 201–208.

Problems associated with the modal phase characteristics of earthquake ground motions are discussed. In particular, the significance of the concept of phase differences in certain types of earthquake ground motions is emphasized. Several applications of this concept are presented and discussed. The main findings are the following: (1) The probability distributions of phase angles contained in most accelerograms of actual earthquake motions are uniform. (2) The probability distributions of their phase differences are normal or close to normal in shape. (3) A correlation seems to exist between the shape of the probability distribution of the phase differences for an earthquake motion and the general shape of the same motion in the time domain. (4) The depiction of the phase wave or the distribution of the phase differences is useful for the detection and elimination of anomalies contained in the earthquake motion record. (5) Use of the phase difference concept, instead of multiplication by a conventional envelope function, results in the improvement of convergence and stability in the iterative process for producing a spectrum-consistent, simulated earthquake motion. (6) Theoretical proof of the above matters appears to be within the bounds of possibility.

● 3.2-37 Ueda, S. and Shiraishi, S., **Earthquake observations on a deepwater terminal,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 23, Nov. 1978, 177–184.

This paper describes earthquake records obtained on a deepwater platform and the ground. Three accelerometers for recording two horizontal components and one vertical component are placed 5 m under the seabed; three accelerometers for recording the same components are placed on the platform; and one accelerometer is placed at an opposite point on the platform. Records of motions have been obtained for four earthquakes since Mar. 1978. These records are analyzed and maximum values of acceleration, velocity, and displacement are determined. Frequency spectra also are computed. These results are compared with analytical results.

● 3.2-38 Shibata, H., Shigeta, T. and Sone, A., **On ground motion records for engineering purpose other than horizontal ground acceleration record,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 24, Nov. 1978, 185–192.

This paper deals with ground motion records other than the ordinary horizontal acceleration record. Several types of ground motions have been observed at the Chiba Field Station, Inst. of Industrial Science, Univ. of Tokyo. The characteristics of the ground motions are discussed, and their significance for the seismic-resistant design of industrial facilities, such as three-dimensional piping systems, cylindrical oil storage tanks, spherical tanks, nuclear reactor core assemblies, etc., is assessed. Long-period ground motions, torsional ground motions, and multidimensional ground acceleration are examined.

● 3.2-39 Tsuchida, H. and Kurata, E., **High frequency components of seismic ground motions studied with observed data** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 21, Nov. 1978, 161–168.

High-frequency components of seismic ground motions are one of the topics of growing interest in earthquake engineering. While the seismic stability of most civil engineering structures is influenced by the frequency components up to several hertz, seismic stresses of structural members are influenced by higher frequency components as well. In addition, high-frequency components have a great influence on various kinds of equipment and other apparatus, including parts of lifeline systems.

Most strong-motion accelerographs used in the past in Japan have had low-frequency characteristics; thus a constant magnification level is maintained only up to several hertz. The SMAC-B2 accelerographs have such frequency characteristics, and these accelerographs have been used to obtain most of the records for the Port and Harbour Research Inst. observation network. This has caused difficulty in studying high-frequency components. However, the observation network also has accelerographs of another type, called the ERS accelerograph, which maintains a 90% magnification level in the frequency range 0.18–50 Hz.

The ERS accelerograph records examined in this paper are classified into three groups: those records with frequency components higher than 15 Hz, which cannot be reproduced from SMAC-B2 accelerograph records; those records with frequency components up to 15 Hz, which possibly can be reproduced from SMAC-B2 records; and those records with frequency components up to 5 Hz, which can be recorded with fidelity by SMAC-B2 accelerographs. The response spectra for records with predominant

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frequency components between 15–30 Hz are presented. It is found that ground motions containing significantly high frequency components have been recorded on rocks or hard sandy gravels for which the N-values are higher than 50.

● 3.2-40 Shiono, K., **Identification of wave types in strong motions by means of down-hole array** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 37, Nov. 1978, 289–296.

Strong-motion records obtained by a down-hole array are analyzed; special attention is given to the identification of wave types. The array of four three-component moving coil-type seismometers is installed at Ukishima, Kawasaki, Japan. The instruments are placed at the surface and at depths of 27, 67, and 127 m. The seismic profile around the station has already been investigated. Two records are studied in the frequency range 0.3 - 3 Hz. Underground and surface spectral amplitude ratios and phase differences are analyzed. Theoretical amplitude ratios and phase differences are computed for vertical incident standing P- and S-waves and for Rayleigh and Love waves and compared to observed data. Using three-component surface records, frequency-time characteristics, frequency characteristics, and particle motion also are analyzed. The results indicate that the vertical component is composed of vertical incident standing P-waves and that the horizontal component is composed of S-waves with the same behavior. The wave types do not change for the length of the records although the frequency contents vary significantly with time.

● 3.2-41 Tanaka, T., Yoshizawa, S. and Osawa, Y., **Characteristics of strong earthquake ground motion in the period range from 1 to 15 seconds** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 34, Nov. 1978, 265–272.

It is important to clarify the characteristics of strong earthquake ground motion in the period range from 1 to 10 or more seconds in order to investigate the seismic-resistant properties of long-period structures such as highrise buildings, long-span bridges, large-sized liquid storage tanks, etc. For this purpose, seismograms from 25 earthquakes recorded at Tokyo with long-period strong-motion seismographs have been analyzed using various spectrum analysis techniques.

The Fourier displacement spectra show different shapes for different epicentral distances and focal depths, i.e., nearby earthquakes have a few small peaks in the shorter period range, while the moderately distant earthquakes have a large single peak in the longer period range. Most of the spectra, however, have the largest peak at a period of around 8 sec. This spectral feature strongly reflects the deep underground structure, down to about 2.3 km, of the Tokyo area, and the predominant period coincides with that for S-waves and Love waves as expected from the underground structure.

The wave types of the major portions of the seismograms were examined by means of the response envelope spectrum, and clear dispersion was found for the transverse component of seismograms of earthquakes with very shallow focal depth (0-10 km) and epicentral distance of about 100 km or more. Dispersion curves of group velocity were also obtained by moving-window Fourier analysis. These results show that the ground motion caused by such earthquakes mainly consists of fundamental mode Love waves. A danger of this type of earthquake motion is the lengthening of the duration of structural vibration.

Through the two-dimensional response analysis of a one-degree system, the strength of the ground motion of 25 earthquakes was evaluated and compared with that for the El Centro (1940) and Hachinohe (1968) accelerograms, which are now commonly used in the earthquake-resistant design of structures. One important conclusion is that the long-period structures situated above thick sedimentary layers as in Tokyo are expected to be severely stressed when a very shallow earthquake with magnitude greater than 7.0 occurs at a distance of approximately 100 km from the site.

● 3.2-42 Kudo, K., **Surface waves as input motions to a large scale structure** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 35, Nov. 1978, 273–280.

This paper demonstrates that surface waves as well as body waves are important for the study of strong earthquake motions as input to a large-scale structure. A spectral acceleration amplitude at far-field, extended from the excitation theory of surface waves, was derived by assuming a simple source model and the underground structure in and around Tokyo. The amplitude was expressed in terms of earthquake magnitude and epicentral distance, using empirical relations of source factors. The spectral amplitude was extended to express the velocity response spectrum for a single-mass system and the formula of a base shear coefficient. These simplified expressions were compared with the ones derived by Ohta and Kagami. It was found that a spectral acceleration amplitude of surface waves exceeds that of body waves when the focal depth is around 10 km and the epicentral distance is larger than 50 km. Generally speaking, the longer the natural period of a structure, the smaller the damping constant. A response amplification of a structure with a small damping constant is affected strongly by the number of waves caused by

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surface-wave dispersion. For example, based on a recommendation of the Architectural Inst. of Japan, the acceleration amplitude in Tokyo for a structure is less than 10 gal at an epicentral distance of approximately 100 km.

● 3.2-43 Kobayashi, Y. and Fujiwara, T., **Ground motions of longer periods in strong earthquakes,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 33, Nov. 1978, 257-264.

Seismograms from the 1964 Niigata earthquake and from the 1968 Tokachi-oki earthquake and its largest aftershock are analyzed. The seismograms were recorded by JMA-type strong-motion seismographs. Procedures for data processing are described. Response spectra are computed for periods from 2 to 50 sec, and the results are compared with those of SMAC records at almost the same sites in the same period range, yielding satisfactory agreement. The frequencies of relative-velocity spectra are almost flat in the period range computed, which implies a ω-square law in that range. Since levels of spectra at several sites suggest that site conditions have a strong influence, a formula for the level of spectra as a function of earthquake magnitude, distance, etc., could not be determined.

● 3.2-44 Abdel-Ghaffar, A. M., **Engineering data and analyses of the Whittier, California earthquake of January 1, 1976,** *EERL 77-05,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Nov. 1977, 254.

The eleven strong-motion accelerographs located near the epicenter of the Whittier earthquake of Jan. 1, 1976, were installed in one multistory building and on two dams and two reservoirs. Although the earthquake had a Richter magnitude of only 4.2, and thus did not qualify as a potentially destructive earthquake, a peak acceleration of 18% g was recorded by the closest accelerograph, 2.2 miles from the epicenter at the Orange County Reservoir. Because the earthquake motions were recorded at five different locations, all within 10 miles of the epicenter, a good picture of the disturbance was provided. The analysis of the records would have had more engineering significance if the magnitude of the earthquake had been great enough for the structural vibrations to have caused some overstress, but even with ground motion of such short duration the recorded accelerations provided useful information. The analysis of the motions of the Whittier Building shows that even in a relatively simple structure excited by moderate ground shaking, the vibrations are quite complex. The motion recorded on the roof of the Diemer Reservoir clearly showed that the roof vibrated with appreciable beam-type deformations, thus revealing an undesirable structural flexibility. The two accelerographs on the two abutments of Carbon Canyon Dam provided valuable information on the degree of correlation between the earthquake motions at two ends of a dam.

● 3.2-45 Converse, A., **Strong-motion information retrieval system—user's manual,** *Open-File Report 79-289,* U.S. Geological Survey, Menlo Park, California, Sept. 1978, 49.

The Strong-Motion Information Retrieval System was developed as part of the Strong-Motion Program operated by the U.S. Geological Survey for the National Science Foundation. Anyone involved in earthquake engineering may access the system, and it should prove to be of considerable value in the aftermath of a major earthquake by providing a central source of current information for strong-motion data users. Information about earthquakes that have produced significant strong-motion records, the recording sites, the records recovered, and the extent of the analysis that has been performed on the records is available from the system. Most of this information is related to the network maintained by the U.S. Geological Survey for NSF and other agencies, but the system may be expanded in the future to include information about other strong-motion networks as well. This manual introduces new users to the system and supplies experienced users with complete descriptions of all the items that may be retrieved from the system.

● 3.2-46 Trifunac, M. D., **Uniformly processed strong earthquake ground accelerations in the western United States of America for the period from 1933 to 1971: pseudo relative velocity spectra and processing noise,** *Report No. CE 77-04,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Sept. 1977, 219.

This report describes the frequency-dependent signal-to-noise ratio for 186 uniformly processed strong-motion accelerograms recorded between 1933 and 1971 in the western United States. These data represent the first uniformly processed batch of data from the ongoing program for the recording and processing of significant accelerograms of strong earthquake ground motion in the western U.S. The signal-to-noise ratio is estimated by comparing the pseudo relative velocity (PSV) spectrum of each of the records with an average PSV spectrum of digitization noise.

● 3.2-47 Trifunac, M. D. and Lee, V. W., **Uniformly processed strong earthquake ground accelerations in the western United States of America for the period from 1933 to 1971: corrected acceleration, velocity and displacement curves,** *Report No. CE 78-01,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Feb. 1978, 220.

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This report presents corrected acceleration, velocity, and displacement curves for recordings from the free-field or the basements of buildings. These data were recorded in the western United States between 1933 and 1971. In an earlier report, a uniform frequency band between 0.07 Hz (or 0.125 Hz) and 25 Hz was chosen for all records. In this report, each record is analyzed separately. Whenever the signal becomes smaller than the amplitude of average plus one standard deviation of digitization noise, the original low-frequency limit (0.07 Hz or 0.125 Hz) is replaced by a higher cutoff frequency to eliminate digitization and processing noise. For many records this improves the accuracy with which computed velocity and displacement curves approximate actual ground motions.

● 3.2-48 Omote, S. and Narahashi, H., **A study on amplitude of vertical component in the strong earthquake motions** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 138, Nov. 1978, 1097–1104.

This paper studies the ratio R of the maximum vertical amplitude acceleration to that of the horizontal amplitude. Acceleration seismograms recorded at the Tsukuba Seismological Station of the Earthquake Research Inst. are analyzed and compared with records from SMAC seismographs. The main results include the following. (1) The maximum acceleration amplitude of the vertical component appears in the main portion of the ground vibration. It appears rarely in the first phase of the ground motion. (2) The R in this study was definitely larger than the R values obtained from the SMAC records. This may be attributed to the fact that the epicentral distance of the earthquakes in this study were smaller than those of the SMAC records. With regard to the R values of this study, in which epicentral distances were distributed in the range from 4 km to 100 km, no clear relationship of the R-Δ dependency was observed. (3) No definite relationship between the magnitude of an earthquake and the R value was observed. (4) A difference in R values was observed for earthquakes occurring in different regions.

● 3.2-49 Brancaleoni, F., Gavarini, C. and Petrangeli, M. P., **On the influence of the horizontal ground acceleration components acting contemporaneously on a dissymmetric structure,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. III, 605–628. (For a full bibliographic citation, see Abstract No. 1.2–7.)

This paper describes the results of a study on the influence of ground motion direction change during earthquakes. A study was conducted on three models of a multistory RC building, using time history and spectrum analysis techniques. Five records of the May 6, 1976, Friuli earthquake are used along with two conventional spectra. A comparison is made between one horizontal component of the ground motion and two components acting simultaneously.

● 3.2-50 Bernreuter, D. L., **A geophysical assessment of near-field ground motion and the implications for the design of nuclear installations,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. II, 429–459. (For a full bibliographic citation, see Abstract No. 1.2–7.)

This paper discusses in depth the various methodologies currently available to predict the near-field ground motion from an earthquake. The limitations of the various methods are discussed in some detail in light of recently available data. It is shown that—at least for California earthquakes—a wide variation in the peak ground motion can occur for an earthquake with a given magnitude. The change in the spectral content of the ground motion is given as a function of earthquake magnitude and peak ground acceleration. It is shown that the large g values associated with small earthquakes are relatively unimportant in a design provided that structures have a modest amount of ductility. Data recently obtained from the Friuli earthquake also are examined. Although not all the geophysical data are currently available, the provisional conclusion is reached that the relationship between the strong ground motion from the Friuli earthquake and its source parameters is the same as for the western United States.

● 3.2-51 Basili, M. *et al.*, **Strong-motion records of Friuli earthquake,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. II, 375–386. (For a full bibliographic citation, see Abstract No. 1.2–7.)

When the Friuli region was hit by an earthquake on May 6, 1976, the Ente Nazionale per l'Energia Elettrica's accelerometer network was already in operation in the area and thus the main shock was recorded by eleven stations. In the following forty-eight hours, additional mobile stations were installed on different types of soil and structures to record new shocks for the purpose of acquiring important seismological and engineering data on the dynamic response of the soils and on the soil-structure interaction. The paper briefly describes the criteria followed in processing these recordings, and the several recordings obtained during this period are listed. Because of the location of the mobile stations, results of interest were obtained, particularly with regard to the near-field dynamic behavior of the soils.

● 3.2-52 Barbreau, A. *et al.*, **Study of the aftershocks of the May 6, 1976 Friuli earthquake** (Etude des repliques du seisme du 6 mai 1976 au Frioul, in French), *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the*

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Antiseismic Design of Nuclear Installations, **Vol. II,** 342–374. (For a full bibliographic citation, see Abstract No. 1.2–7.)

In collaboration with the Comitato Nazionale per l'Energia Nucleare, the French Dept. de Surete Nucleaire of the Commissariat a l'Energie Atomique installed temporary seismic stations in Friuli following the May 6, 1976, earthquake in order to study shocks subsequent to the main shock. The instruments recorded a number of events of varying size, including the large earthquakes of September 11 and 15, 1976, the magnitudes of which were close to 6. A macroseismic study was conducted in the region of the stations. From these recordings, approximately one hundred components were utilized and corresponding response spectra calculated. Variations in these spectra were studied as a function of such earthquake characteristics as magnitude and focal distance. These spectra are characteristically high frequency.

● 3.2–53 Petrovski, D. and Naumovski, N., **Analysis of strong motion records of the Friuli earthquake obtained in Yugoslavia,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. II,** 322–341. (For a full bibliographic citation, see Abstract No. 1.2–7.)

The Inst. of Earthquake Engineering and Engineering Seismology in Skopje has developed a procedure for strong-motion data processing aimed to obtain more exact information. Some important characteristics of this procedure are discussed. The procedure has been applied to several records of the Friuli earthquake obtained in Yugoslavia which are of engineering interest, and the results have been analyzed. In addition, comparison is made with other strong ground motion data. This comparison emphasizes the importance of the frequency composition of ground motion upon structural behavior during strong earthquakes.

● 3.2–54 Mihailov, V., **Strong-motion records of Friuli earthquake 1976,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. II,** 306–321. (For a full bibliographic citation, see Abstract No. 1.2–7.)

The earthquakes that occurred during 1976 in Friuli, close to the Yugoslav-Italian border, originated from the known seismogene zone Friuli-Carnia. In this zone, the regional longitudinal faults intersect with the transversal fault zone that is connected to the valley of the Tagliamento River. Geological destruction occurred in this zone during the Quaternary period. The considerable seismological activity manifested during 1976 and the accelerograms recorded in the region of Yugoslavia show good correlation with the stretching direction of the fault dislocations. This paper presents the basic tectonic and seismological characteristics of Friuli and the data of 32 recorded accelerograms of the earthquakes that occurred on May 6 and Sept. 15, 1976 and their strong aftershocks.

● 3.2–55 Crouse, C. B., **Prediction of free-field earthquake ground motions,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 359–379. (For a full bibliographic citation, see Abstract No. 1.2–11.)

Existing strong-motion data and the work of previous researchers have been studied with regard to the problems in predicting the spectra of free-field earthquake ground motions. The main problems associated with the predictions of both Fourier and response spectra that are addressed in this paper are the effects caused by several types of soil-structure interaction and local soil conditions and the possible biasing of spectral predictions from the use of a large amount of data from the 1971 San Fernando earthquake. In general one type of soil-structure interaction may have significantly modified the ground motions recorded in multistory buildings with relatively large base dimensions and foundation masses. This type of interaction was a suppression of high-frequency wave amplitudes by the foundations of these buildings. As a result, differences in spectra that previously have been attributed to local soil conditions may be caused in part by this type of soil-structure interaction. Surface wave effects and the use of Japanese accelerograms, uncorrected for the transducer response of the recording instrument, could also contribute to spectral differences attributed to local soil conditions.

A comparison was made between the spectra predicted using two Fourier spectra attenuation relations, one derived from a small amount of San Fernando data and another derived using all San Fernando data. The results of this comparison indicate that the predominance of San Fernando data can lead to much higher estimates of the spectral levels in the near field when epicentral distances are used in the derivation of the attenuation relation. Response spectra derived exclusively from San Fernando data are similar to response spectra from other southern California earthquakes of comparable size and similar local soil conditions and for which the source-to-recording station distances are fairly well known. However, San Fernando response spectra do not show similar agreement with response spectra from northern California and Washington earthquakes where the location of the fault ruptures are not well known.

● 3.2–56 Johnson, J. A. and Traubenik, M. L., **Magnitude-dependent near source-ground motion spectra,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 530–539. (For a full bibliographic citation, see Abstract No. 1.2–11.)

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Currently accepted procedures for estimating design response spectra such as those proposed by Hall et al. and Mohraz are generally independent of magnitude. Based on these procedures, normalized, constant spectral shapes are developed which are then scaled to a prescribed magnitude-dependent peak acceleration. These procedures do not take into account that the amplitude and shape of the long-period portion of a spectrum should change to reflect increased long-period motions associated with increasing magnitude.

A study was performed for near-source rock sites using a procedure similar to that proposed by Mohraz. The procedure was modified to include the quantitative incorporation of magnitude dependency. Ground motion ratios and amplification factors for acceleration, velocity, and displacement were estimated for a range of magnitudes. Near-source response spectra for magnitude 7, 7-1/2, and 8 events were constructed, and the results were compared with those of Mohraz. The resulting spectra are nearly identical at short periods. However, the amplitude in the long-period portion of the response spectrum systematically increases as a function of magnitude. Results of the study indicate the feasibility and importance of incorporating magnitude dependency into near-source design spectra.

● 3.2-57 Papastamatiou, D., **Contributions of early instrumental seismic recordings to engineering analysis,** *Instrumentation for Ground Vibration and Earthquakes,* Proceedings of the Conference of the Society for Earthquake and Civil Engineering Dynamics, Institution of Civil Engineers, London, Paper 12, 1978, 119–124.

Valuable information on large near-field earthquakes may be extracted from early far-field seismic recordings. This information is unique because earthquakes of this size have not been repeated within the period of instrumental seismology.

● 3.2-58 Medearis, K. G. and Wilson, J., **Analysis and correction of ground and structure motion recordings,** *Instrumentation for Ground Vibration and Earthquakes,* Proceedings of the Conference of the Society for Earthquake and Civil Engineering Dynamics, Institution of Civil Engineers, London, Paper 11, 1978, 113–117.

The importance of proper corrections to ground and structural motion recordings to eliminate low-frequency drift and high-frequency noise cannot be overemphasized. Analytical results based on uncorrected record data are often significantly in error. This paper describes a record correction procedure which proved to be of value in a recent seismic response research effort.

● 3.2-59 Chiu, H.-C. and Liu, W.-S., **Catalog of strong-motion accelerograph stations and records in Taiwan,** Inst. of Earth Sciences, Academia Sinica, Taipei, Taiwan, Dec. 1978, 31.

In 1971, a comprehensive earthquake observation and research program was instituted by the National Science Council, Republic of China. Installation of a strong-motion accelerograph network throughout the Taiwan area was one major item of the program. Since then, the number of instruments has increased yearly. By the end of 1978, there were 42 SMA-1 accelerographs operating in the country. A list of recording sites is included in this publication. In the past few years, several tens of records were collected. However, most of these records contain accelerations barely above the trigger level of 0.01 g set for these instruments. The situation changed on Apr. 14, 1976, when a magnitude 5.4 earthquake in southwestern Taiwan produced unusually high accelerations at some sites. Several earthquakes with magnitudes above 6.0 occurred during 1978, resulting in a number of records of engineering interest. The purpose of this publication is to inform interested researchers and engineers of the existence of these records for use in the dynamic design of earthquake-resistant structures and for seismological studies.

The records are arranged by individual earthquakes in chronological order. Information about the origin time, epicenter coordinates, focal depth, and Richter magnitude of each earthquake are provided. In addition, the observed intensity values on the Central Weather Bureau intensity scale, which is essentially the same as the JMA intensity scale, are given for reference.

● 3.2-60 Hodder, S. B. *et al.*, **Strong motion records of the Milford Sound earthquake 1976 May 4,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 11, 3, Sept. 1978, 184–190.

The strong-motion records obtained during the Milford Sound earthquake of May 4, 1976, are of interest since the assigned intensities are exceptionally low for an earthquake of magnitude 7. The recorded ground motions presented are in the format proposed for publication of significant earthquakes recorded by the New Zealand strong-motion network. It is seen that the ground motions are consistent with the low intensities assigned.

● 3.2-61 **Santa Barbara earthquake, August 13, 1978: data report,** Kinemetrics Inc., Pasadena, California, 1978, 10.

● 3.2-62 Porter, L. D., **Compilation of strong-motion records recovered from the Santa Barbara earthquake of 13 August 1978,** *Preliminary Report* 22, California Div. of Mines and Geology, Sacramento, Oct. 20, 1978, 43.

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

● **3.2-63** **June 12, 1978 Miyagi-Ken-oki earthquake,** *Report on Strong-Motion Accelerograms No. 15,* Japan National Research Center for Disaster Prevention [Tokyo], July 1978, 18.

This report contains the strong-motion accelerogram records from the June 12, 1978, Miyagi-Ken-oki earthquake. A map showing JMA intensities is included.

● **3.2-64** Hattori, S. and Nakajima, N., **Stability of spectra of micro-tremors,** *Bulletin of the International Institute of Seismology and Earthquake Engineering,* **16,** 1978, 89–103.

This report presents a stable microtremor spectrum by averaging the spectra of microtremors observed at many different times. The microtremors were observed nearly 100 times every two hours at the Building Research Inst. in Japan and the mean spectra were obtained. The same procedures were made in three different periods. The mean spectra above 10-20 times the observations were very stable and the predominant periods were 0.3 sec and 1.2 sec.

● **3.2-65** Espinosa, J. M. *et al.,* **Preliminary report on the earthquakes of November 29, 1978, in the state of Oaxaca** (Informe preliminar sobre los sismos del 29 de Noviembre de 1978 en el Estado de Oaxaca, in Spanish), *IPS-4,* Inst. de Ingenieria, Univ. Nacional Autonoma de Mexico, Mexico City, Dec. 8, 1978, 47.

● **3.2-66** Brady, A. G. and Perez, V., **Strong-motion earthquake accelerograms, digitization and analysis, 1972 records,** *Seismic Engineering Data Report, Open-File Report 78-941,* U.S. Geological Survey, Menlo Park, California, Oct. 1978, 128.

This is the third of a series of reports planned to include the results of digitization and routine analyses of strong-motion earthquake accelerograms published by the U.S. Geological Survey. Serving as a model for this effort is the collection of data reports published by the Earthquake Engineering Research Lab. of the California Inst. of Technology, Pasadena, during the years 1969–1975 and covering the significant records of the period from 1933 up to the San Fernando earthquake of Feb. 9, 1971. Earlier reports in the present series have covered the significant records of 1971 subsequent to San Fernando (Open-File Report 76-609) and Peru records from 1951 to 1974 (Open-File Report 77-587). The present report includes a selection of 1972 records from California, Managua, and Sitka, Alaska.

● **3.2-67** **Strong-motion earthquake accelerograms: digitization and analysis, 1971 records,** *Open-File Report 76-609, Seismic Engineering Data Report,* U.S. Geological Survey, Menlo Park, California, July 1976, 117.

This is the first of a series of reports planned to include the results of digitization and routine analyses of strong-motion earthquake accelerograms published by the U.S. Geological Survey. Serving as a model for this effort is the collection of data reports published by the Earthquake Engineering Research Lab. of the California Inst. of Technology during the years 1969–1975 and covering the significant records of the period from 1933 up to the San Fernando earthquake of Feb. 9, 1971. This report covers the significant records of 1971 subsequent to the San Fernando earthquake. The following five records are included: (1) Isabella Dam, California (auxiliary dam abutment), Mar. 8, 1971; (2) Adak, Alaska, U.S. Naval Base (seismic vault), May 1, 1971; (3) Santiago, Chile (Univ. of Chile), July 9, 1971; (4) Ferndale City Hall, California (ground level pier), Sept. 12, 1971; (5) Lima, Peru (Inst. Geofisico), Nov. 29, 1971.

3.3 Artificial and Simulated Earthquake Records

● **3.3-1** Jurkevics, A. and Ulrych, T. J., **Representing and simulating strong ground motion,** *Bulletin of the Seismological Society of America,* **68,** 3, June 1978, 781–801.

This paper presents a procedure for representing and synthesizing strong-motion accelerograms for computing structural response in earthquake-prone areas. The procedure models the target earthquake as a nonstationary second-order autoregressive (AR) process. The AR parameters are determined either by segmenting the record or by continuously updating the parameters in a time-adaptive manner. The outlined procedure is applied to the simulation of accelerograms, using the Orion Boulevard recording of the 1971 San Fernando earthquake as a target.

● **3.3-2** Kaul, M. K., **Spectrum-consistent time-history generation,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM4,* Proc. Paper 13919, Aug. 1978, 781–788.

A method is presented for generating an acceleration time history to match a specified absolute acceleration response spectrum. The relationship between the change in time history required to effect a specified change in its spectrum is established and forms the basis for an iterative procedure for generating a spectrum-consistent time history. It is shown that a high degree of accuracy can be achieved in a few applications of the iterative procedure.

● **3.3-3** Archuleta, R. J., Joyner, W. B. and Boore, D. M., **A methodology for predicting ground motion at specific sites,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 255–265.

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An important development in current research on earthquake ground motion is the synthesis of ground motion records based on the physics of a propagating fracture. Different techniques are used for generating synthetic records depending upon the frequency range of interest. For frequencies below about 1-2 Hz, a *finite element* method was used to simulate a propagating fracture; for higher frequencies, a stochastic dislocation model was used. Use of the finite element method enabled the simulation of an earthquake with three-dimensional geometry. The *ground motions from two hypothetical earthquakes* differing only in their shear stress distribution with depth are computed. On the free surface, the maximum particle velocity is contoured. From such contours, the areas most likely to suffer damage during an earthquake can be approximated. The fault slip generated by a propagating stress relaxation has been used as input for the stochastic model. Acceleration is computed using a statistical source model in which the amplitude of the dislocation-time function varies randomly along the fault while the shape of the function and the rupture velocity are constant.

● 3.3-4 Paramzin, A. M., **On estimation of real earthquake excitation damping,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-39, 1978, 297-303.

A new quantitative method is presented for approximating the damping of real earthquake ground motion as an irregular stochastic process. A sequence of operations using a block of tabulated typical points of an accelerogram is described. A stable damped time-history distribution over all of the records has been found for the accelerograms of six severe earthquakes. The obtained damping characteristics are compared with the damping value used for the standard spectral curve in the U.S.S.R. seismic code. *It is suggested that the technique be used to analytically* approximate an earthquake by statistically processing all available accelerograms.

● 3.3-5 Wiggins, R. A. *et al.*, **Modeling strong motions from major earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 693-699.

A set of programs for computing synthetic strong-motion seismograms for hypothetical earthquake ruptures has been implemented. The modeling procedure consists of three parts: (1) characterization of the fault slip at each point on the rupture surface, (2) synthesis of Green's functions of the wave propagation from points on the rupture surface to receivers, and (3) convolution of Green's functions with the rupture motion. The slip function incorporates a very rapid initial displacement to simulate observed slip behavior near the crack tip. The computed Green functions are the complete response for a point dislocation in a layered viscoelastic halfspace over the frequency range from 0.02 to 20 Hz. It is assumed that the rupture spreads from the hypocenter at some fraction of the shear velocity and that the rupture remains coherent only for short distances. Parametric studies indicate that *high-frequency radiation is strongly controlled by the* motion at the crack tip, while low-frequency radiation is controlled by the magnitude and duration of the total slip. In addition, rupture propagation strongly focuses high-frequency radiation. Other relevant earthquake processes include rupture coherence or lack of coherence, propagation paths and wave types, and wave attenuation with distance.

● 3.3-6 Wu, F. T., **Prediction of strong ground motion using small earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 701-704.

A method is proposed for using seismograms obtained from small earthquakes along an active fault to generate strong-motion seismograms at a site.

● 3.3-7 Swanger, H. J. and Boore, D. M., **Simulation of strong-motion displacements using surface-wave modal superposition,** *Bulletin of the Seismological Society of America,* 68, 4, Aug. 1978, 907-922.

Synthetic seisomograms constructed by addition of surface-wave modes in a layered halfspace are compared to Cagniard-de Hoop calculations of Heaton and Helmberger and to ground displacement recordings near El Centro, California, to examine the applicability of modal superposition as a means of simulating ground motion of possible engineering interest. Modal solutions of flat earth problems are desirable because of the modest cost involved and the versatility of the method in simulating extended sources and anelastic damping. *P-SV* and *SH* motions can be computed with almost equal ease. The comparisons show that in sedimentary structures surface waves can dominate ground displacement motion at epicentral distances of only a few source depths. Superposition of the higher modes often approximates quite well impulsive arrivals with analogies to refracted and reflected rays.

Ground displacement recordings of El Centro from the 1968 Borrego Mountain earthquake are modeled using a multilayered geological structure and a source model based on independent studies. The gross character of the records appears to be insensitive to the details of the source. Both point sources and propagating sources with horizontal dimensions larger than half the epicentral distance give reasonable fits to the observed transverse motion. This insensitivity appears to be due to a complex interaction between rupture propagation and the surface-wave dispersion. By using the integrated El Centro accelerogram,

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which may have more reliable amplitude information than the Carder displacement record used in other studies, the moment is estimated to be 12 x 10^{25} dyne-cm. This is similar to values found from studies of teleseismic data.

● 3.3-8 Duarte, R. T., **A stochastic model of non-stationary ground motion,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-24, 1978, 175-182.

This paper presents a stochastic model of earthquake vibration constructed from time segments of stationary Gaussian processes. The method takes into account important features of strong ground motion, such as peak ground motion, magnitude, distance to the fault, geological site characteristics, and response spectra. An algorithm for artificial earthquake vibration is also presented.

● 3.3-9 Kameda, H., **Stochastic process models of strong earthquake motions for inelastic structural response,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 71–85. (For a full bibliographic citation see Abstract No. 1.2–3.)

Methods for modeling strong-motion accelerograms are discussed. Stochastic process models are developed so that elastoplastic structural response, including deformation and total hysteretic energy, will agree in the mean with the corresponding recorded accelerograms. Intensity, frequency content, and duration are incorporated in a consistent manner. Conventional amplitude-modulated stationary processes are reviewed first. On this basis, the significance of extension to evolutionary process models is discussed, and a preliminary analysis is made.

● 3.3-10 Wong, H. L. and Trifunac, M. D., **Synthesizing realistic ground motion accelerograms,** *CE 78-07,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Sept. 1978, 93.

In this report a method is presented for generating artificial strong-motion accelerograms for use in engineering design. The method characterizes strong shaking in terms of (1) earthquake magnitude and epicentral distance, or (2) modified Mercalli intensity at the recording station. The effects of the geologic environment on the amplitudes and duration of strong shaking have been included. The resulting accelerograms have Fourier amplitude spectra and frequency-dependent duration characteristics which agree with observed strong-motion accelerations. The phase and group arrival times are chosen to agree with the dispersion model at the site.

● 3.3-11 Kubo, T. and Suzuki, N., **An application of synthetic earthquake ground motions to response analysis—simulation of earthquake ground motions,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 12, Nov. 1978, 89–96.

Through the use of Fourier transformation, two types of stochastic modeling of earthquake ground motion are discussed. Twenty samples of synthetic motion are generated by each of these two models, which simulate actual recorded motions. Using these motions, characteristics of synthetic motions, such as the cumulative energy distribution (the integration of square acceleration), the maximum elastic response, and the maximum elastoplastic response, are evaluated. The results are statistically compared with those obtained from a recorded earthquake motion.

● 3.3-12 Kubo, T. and Penzien, J., **Analysis of three-dimensional earthquake ground motion along an orthogonal set of principal axes,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 13, Nov. 1978, 97–104.

An orthogonal set of principal axes is defined for a three-dimensional earthquake ground motion. These principal axes are obtained along which the corresponding components of motion have maximum, minimum, and intermediate values of variances and have zero values of covariances. This property indicates that the components of motion along principal axes are fully uncorrelated with one another. Analysis of real earthquake motions suggests that earthquake accelerograms are well represented by Gaussian random processes. In a statistical sense, the corresponding three components of motion along a set of principal axes are independent of one another.

Using the concept of an orthogonal set of principal axes and applying the moving-window technique in the time domain to the accelerograms recorded during the San Fernando earthquake of 1971, analyses of three-dimensional earthquake ground motions are carried out along their principal axes. In these analyses, time-dependent characteristics of principal variances and directions of principal axes of motion are determined. Results of the analyses reveal a tendency of directions of the major principal axis of motion, or in some cases the intermediate principal axis, to point towards the fault slip zone. It is concluded that three-dimensional earthquake ground motions can be generated stochastically by use of mutually independent random processes, provided the components of motion are directed along their corresponding principal axes.

● 3.3-13 Watabe, M. and Tohdo, M., **Research on the simulation of three-dimensional earthquake ground motions, part-I,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 14, Nov. 1978, 105–112.

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This paper analyzes by stochastic methods the various parameters necessary for seismic-resistant design, including the simulation of ground motion. The analysis examines the possibility of using the principal axes proposed by J. Penzien and M. Watabe, stochastic correlations between maxima of horizontal and vertical components, relation between the duration time and the magnitude of the earthquake, response spectral shape expressed in terms of the hypocentral distance and the magnitude of the earthquake, and the new deterministic intensity function concept derived from mathematical models.

● **3.3-14** Watabe, M. and Tohdo, M., **Research on the simulation of three-dimensional earthquake ground motions, part-II,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 15, Nov. 1978, 113–120.

The maximum transient response of structures subjected to nonstationary excitations is theoretically estimated by use of random vibration theories. The effects of damping, frequency, and duration time have been numerically evaluated, and the results verified by computer. Two major procedures for the simulation of three-dimensional earthquake ground motions are introduced. One is a synthetic means of generating and superposing harmonic waves with random phase angles which are then multiplied by a deterministic intensity function. Three independent components are correlated into a new set of coordinates. In the other method, actual sets of accelerograms are also utilized in order to give better sets of phase angles and covariances.

● **3.3-15** Hiromatsu, T., Abe, Y. and Tamaki, T., **Generation of artificial earthquakes for dynamic analysis of nuclear power plants** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 9, Nov. 1978, 65–72.

Recorded earthquake motions are often used as input motions for dynamic analysis of structures. These motions, however, reflect only particular seismic characteristics and local conditions so are not always valid. In order to correct defects in the recorded earthquake motions, it is necessary to generate artificial earthquakes based on stochastic and statistical theory. It is hoped that artificial earthquakes can be used as the input motions at bedrock for the seismic-resistant design of nuclear power plants. This paper examines the generation of artificial earthquakes and the development of computer codes.

To develop the codes, the authors did the following: (1) set up an envelope function and a design response spectrum; (2) generated an acceleration time history; (3) computed the normalized acceleration response spectrum of the generated artificial time history and compared the computed response spectrum with the design response spectrum; (4) if the computed spectrum did not fit the design spectrum, modified the acceleration amplitudes; (5) after the computed spectrum converged to the design spectrum, computed the velocity time history and adjusted the generated acceleration time history.

An example is given for the dynamic analysis of a BWR-type reactor building. Two artificial earthquakes were generated using the developed computer codes. One is for a near earthquake and the other is for a distant earthquake. Comparing the generated artificial earthquakes with the actual recorded earthquakes, it seems that the artificial earthquakes are useful as the input motions at the bedrock for the dynamic analysis of the reactor building. Using one of the artificial earthquakes, the nonlinear responses of the reactor building were also calculated. The authors concluded that these generated artificial earthquakes are practical for use as the input motions for dynamic analysis of nuclear power plants.

● **3.3-16** Kobayashi, J., **Generation of artificial earthquake motions and their applicability for design purposes** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 10, Nov. 1978, 73–80.

A practical method of generating artificial earthquake motions is presented. With this method, artificial waves can be obtained iteratively, and their response spectra compared with the desired mean spectra determined by Seed et al. The properties of twelve artificial waves are examined. The responses of elastic and elastoplastic systems subjected both to simulated and to observed earthquake motions are computed. By comparing the mean values and the standard deviations of the two groups, it was found that the simulated waves proposed are suitable for seismic-resistant design purposes. The variation of Fourier spectra with time histories also is simulated, and results are presented.

● **3.3-17** Kameda, H. and Sugito, M., **Prediction of strong earthquake motions by evolutionary process model,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 6, Nov. 1978, 41–48.

A statistical model is proposed for prediction of strong earthquake motions for given earthquake magnitudes and epicentral distances. The simulation model is introduced by representing the time variation of the evolutionary spectra of the earthquake motion by a simple time function characterized by three frequency-dependent model parameters. The validity of the model for use in seismic design is demonstrated for the peak acceleration and total power as well as for the deformation spectra and hysteretic energy of elastoplastic systems. Frequency-dependent model parameters are then estimated from regression of magnitude and epicentral distance. The correlation between the parameters is also obtained. The proposed model allows generation of sample accelerograms for a given magnitude and distance.

● 3.3-18 Wiggins, R. A., Sweet, J. and Frazier, G. A., **Seismic risk for offshore structures,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3113, 1978, 529–533.

Computation of the seismic risk for a structure depends on several interrelated factors. Of fundamental importance is the proximity of faults capable of sustaining a major slip. Other important factors include the depth range of the dislocation, the strength of the rocks being fractured, the rupture velocity, and the local geologic conditions near the structure. In order to assess the impact of nearby earthquakes on man-made structures, a study has been undertaken to design a simple computer model that simulates strong-motion records near strike-slip earthquakes. Because of the engineering objectives of these simulations, the study is focused primarily on modeling response spectra at frequencies from 1 to 20 Hz. The computer model has been tested by predicting response spectra for the 1940 Imperial Valley, 1966 Parkfield, and 1976 Brawley earthquakes.

● 3.3-19 Kubo, T., **Simulation of three-dimensional strong earthquake ground motions (Part 1: principal axes for ground motion processes)** (in Japanese), *Transactions of the Architectural Institute of Japan, 265,* Mar. 1978, 81–91.

For certain important structural systems such as nuclear reactor facilities, it may be necessary when conducting the dynamic response analysis to consider the multi-component effects of the ground motion input. In the case of simulation of three-dimensional ground motions by using stochastic processes, the question arises of whether the components of motion should be cross-correlated in a statistical sense. If they are correlated, one must specify, in addition to properties which establish the respective components, cross-correlations for the components. In this paper, an orthogonal set of principal axes is defined for three-dimensional ground motion processes. These principal axes are determined to have maximum, minimum, and intermediate values of variance and zero value of covariance. Thus, the corresponding components of motion along the principal axes are fully uncorrelated. Because real earthquake accelerograms are well represented by Gaussian random processes, the three components of motion along a set of the principal axes are statistically independent of one another.

Using the concept of principal axes and applying a moving-window technique to the accelerograms recorded during the San Fernando earthquake of Feb. 9, 1971, time-dependent characteristics of three-dimensional ground motion along a set of principal axes are determined. Results of the analysis indicate a significant correlation between horizontal directions of the major and intermediate principal axes and directions from the recording stations to the fault slip zone. In view of the existence of principal axes, it is concluded that, since they are independent of one another, the three components of motion can be generated in a stochastic manner, provided that a set of axes along which they are directed is treated as a set of principal axes.

● 3.3-20 Kubo, T., **Simulation of three-dimensional strong earthquake ground motions (Part 2: simulation of three-dimensional ground motions)** (in Japanese), *Transactions of the Architectural Institute of Japan, 268,* June 1978, 61–70.

The power spectral density function of a ground motion which describes the frequency content of the motion is one of the most significant properties to be taken into account when generating ground motions by use of stochastic processes. Using a smoothed and normalized Fourier amplitude spectrum, the frequency contents for components of motion along a set of principal axes are determined. Diagrams are given representing a Fourier amplitude spectrum with a moving-window technique, and the time-dependency of frequency contents can be observed for motions of the San Fernando earthquake of Feb. 9, 1971.

A mathematical model to simulate ground motion processes is introduced which can produce nonstationarity in both intensity and frequency content. Using the mathematical model and the results of principal transformation and frequency content of motions along principal axes obtained by analysis of real motions recorded during the San Fernando earthquake, three-dimensional ground motion processes are synthetically generated. The simulated motions have properties and complexities similar to those observed in real accelerograms. Therefore, the model presented is considered adequate.

● 3.3-21 Hoshiya, M. *et al.*, **Multi-dimensional nonstationary earthquake simulation,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 21–28.

A nonstationary cross-spectral concept is proposed for the mutually correlated characteristics of multidimensional seismic processes. A simulation method for such processes is developed by use of a harmonic series model. Example calculations of the cross-spectra are presented for the

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acceleration records of the Millikan Library and the Hollywood storage building during the 1971 San Fernando earthquake. Wave characteristics and the direction of wave propagation are discussed based on the cross spectra and a concept of principal axes proposed in this paper. A simulation of three mutually correlated components of a point as a ground motion similar to that recorded at the Millikan Library is carried out, and the accuracy of the simulation theory is examined.

● 3.3-22 Hoshiya, M. and Hasgur, Z., **AR and MA models of nonstationary ground motion,** *Bulletin of the International Institute of Seismology and Earthquake Engineering,* **16,** 1978, 55-68.

In this paper, multidimensional MA (moving average) and AR (autoregressive) models are proposed for the time domain. The models exhibit nonstationary amplitude and frequency characteristics.

3.4 Seismic Zoning

● 3.4-1 Youd, T. L. and Perkins, D. M., **Mapping liquefaction-induced ground failure potential,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT4,* Proc. Paper 13659, Apr. 1978, 433-446.

Geologic and seismologic information is used together with criteria developed in this paper to make regional maps of liquefaction-induced ground failure potential. Two maps, a ground failure opportunity map and a ground failure susceptibility map, are combined to form the potential map. Ground failure opportunity occurs when seismic shaking is strong enough to produce liquefaction and ground failure in susceptible materials. A correlation between earthquake magnitude and maximum distance from energy source to possible liquefiable sites is used with regional seismicity maps to prepare an opportunity map. The opportunity map has a probabilistic basis. Criteria relating liquefaction susceptibility to sediment type and setting are used with Quaternary geologic maps to derive the susceptibility map. Liquefaction-induced ground failure potential maps are useful for planning, zoning, and decision making. Additional geotechnical studies are required for liquefaction potential determinations at specific sites within the map units.

● 3.4-2 Donovan, N. C., Bolt, B. A. and Whitman, R. V., **Development of expectancy maps and risk analysis,** *Journal of the Structural Division, ASCE,* **104,** *ST8,* Proc. Paper 13972, Aug. 1978, 1179-1192.

Seismic zoning maps previously used in building codes in the United States did not consider the frequency of exposure to earthquakes in different regions. By combining available data on tectonics, regional geology, and seismicity, new maps of the contiguous United States have been drawn. The maps are based on the assumption of uniform risk exposure. Maps are presented for two quantities, effective peak acceleration and effective peak velocity-related acceleration. These two quantities are then used to obtain the lateral design-force coefficients for the design of earthquake-resistant structures. The development of these maps is the first part of a major review of seismic design procedures.

● 3.4-3 Schell, B. A., **Seismotectonic microzoning for earthquake risk reduction,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 571-585.

Seismic-risk evaluations for proposed critical facilities have shown that existing seismic-risk maps are generally inadequate because they are based on a record of seismicity that is too short to assess the potential for future earthquakes. This has led to the development of seismotectonic zonations and microzonations of the type discussed in this paper which are based on a broader data base comprised of both seismologic and geologic parameters. Investigations conducted in the Middle East and western United States are outlined to illustrate the differences in the two types of seismic-risk maps.

● 3.4-4 Cluff, L. S., **Geologic considerations for seismic microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 135-152.

Seismic microzonation studies are most definitive and useful when conducted as integrated multidisciplinary efforts combining data and value judgments from the fields of geology, seismology, geophysics, engineering, and planning. This paper discusses the contributions of geology to interdisciplinary microzonation studies. It points out some of the problems that have developed in attempting to assess and classify seismic hazards and suggests ways of advancing the science of microzonation to allow more realistic assessments of seismic hazards.

● 3.4-5 Anderson, J. G. and Trifunac, M. D., **Application of seismic risk procedures to problems in microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 559-569.

The seismic risk for the Los Angeles, California, metropolitan region is considered. For sites in the area, the spectral amplitudes of shaking with a selected probability of exceedance are a function of location and geologic site conditions (but not including soil types or water table elevations, for example). However, for the sites selected,

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the maximum difference among these amplitudes is smaller than the uncertainty in the estimate of shaking for a single site. It is difficult to justify contouring the expected amplitudes of ground motion with a contour interval significantly smaller than the uncertainty in ground motion for a single site. Thus, at most, only a small number of risk zones (e.g., 2 or 3) may be justified for the Los Angeles metropolitan area.

These results suggest that for metropolitan regions in similar locations it may be better to adopt a uniform level for estimated future amplitude of strong motion for the entire area or for large sub-areas. When and if methods for reducing the uncertainty in estimates of future amplitudes of strong shaking become available, the associated smaller uncertainties in the final result may allow a more detailed zoning of the Los Angeles region.

● 3.4-6 Mau, S. T. and Kao, C. S., **A risk model for seismic zoning of Taiwan,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 367-377.

A hybrid point-line source model is used for the seismic risk analysis of Taiwan. Any point with an earthquake record of magnitude five or larger is recognized as a source. At each source, the rate of earthquake occurrence and the distribution of earthquake magnitude are established separately. A Poisson process is assumed, and the rate of occurrence is estimated using a Bayesian procedure. The resulting occurrence model takes the form of a Polya process. For the magnitude distribution, the commonly used negative exponential distribution is initially assumed. The parameter of this distribution is estimated using a Bayesian procedure. An upper bound and a lower bound are imposed on the distribution. In calculating the ground acceleration at a site resulting from an earthquake at a source, the attenuation distance is measured from the site to a line centered at the source. The orientation of the line is assumed to be parallel to that of nearby faults. A map of contours of acceleration having a 10% probability of being exceeded in 50 years is constructed, and a simplified zoning map is proposed.

● 3.4-7 Kockelman, W. J. and Brabb, E. E., **Examples of seismic zonation in the San Francisco Bay region,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 303-314.

Six examples of seismic zoning at various scales by cities and counties in the San Francisco Bay region show that scientific information can be used effectively in avoiding earthquake hazards and mitigating damage. The zoning method involves postulating an earthquake, grouping geologic materials with similar physical properties, predicting the geologic effects of an earthquake, and combining the geologic effects on a map. The method has been used by the cities of Mountain View, Novato, and San Francisco and the counties of Marin, Santa Clara, and San Mateo to develop zones which were used as a basis for their general plans, seismic safety plans, development policies, or ordinances.

● 3.4-8 Bell, E. J., Trexler, D. T. and Bell, J. W., **Computer-simulated composite earthquake hazard model for Reno, Nevada,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 471-483.

A computer-simulated earthquake hazard model was developed for the Reno 7 1/2-min quadrangle in western Nevada. Relevant geologic, geophysical and engineering data for the Reno quadrangle were compiled to develop specific knowledge of the physical environment of seismic loading, including depth to the water table, distribution of potentially unstable slopes (defined by topography, microclimate, and bedrock and soil characteristics), and the space-time characteristics of faults. Probable range and finite limits for geologic processes as sources of earthquake-related hazard parameters were determined. Seismic response of the geologic units was estimated by the rigidity product (i.e., the product of the shear wave velocity and density) with three alluvial unit groups (I, II, III) and one bedrock group (IV) defined by similar rigidity product values. Alluvial units II and III were modified to indicate areas with less than 200 ft depth to bedrock. Faults ranked on the basis of age of last movement, slopes of 25% or greater, and areas of depth to ground water less than 60 ft (18 m) were combined with the seismic response to produce three individual hazard elements. The potentials for slope instability, liquefaction and differential compaction, and surface faulting are the seismic hazard elements considered for the Reno area. The composite earthquake hazard map depicts the best estimate of the total potential seismic hazard for a particular area within the Reno 7 1/2-min quadrangle by summing the individual hazard elements.

The model can be adapted to other regions for use at detailed scales of 1:24,000 or larger. The dynamic nature of the model allows the seismic zonation to be updated as new data become available. The sequential structural format can expand to incorporate all locally significant site parameters without minimizing the dynamic range of parameter values or the scaling factors for each element in the composite earthquake hazard analysis.

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● 3.4-9 Fischer, J. A. and McWhorter, J. G., **The microzonation of New York State: progress report no. 2,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 329–340.

Six years ago at the First International Conference on Microzonation, the authors described their interpretation of the spatial relationship of New York State earthquakes to regional tectonics and the possible effects of New York seismicity upon construction. Since that time much information has been developed from nuclear power plant studies and from New York State Geological Survey research. Of particular interest have been fault studies along the south shore of Lake Ontario and in southeastern New York/northeastern New Jersey. These studies have utilized geologic and geomorphic mapping, geophysical surveying, and fluid-inclusion techniques. Geodetic measurements, earthquake fault plane analyses, and a number of in-situ stress measurements have aided in understanding the geologic history and neotectonics of New York and New Jersey. This progress report reviews the recent studies, describes their effects upon the previous attempt at microzonation, and discusses the technical and geographical areas of needed research.

● 3.4-10 Patwardhan, A. S., Tillson, D. D. and Nowack, R. L., **Zonation for critical facilities based on two-level earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 485–496.

The seismic design of critical facilities is based on two levels of earthquakes. Seismic zonation can be used in the siting of such facilities to identify areas that have a higher potential for containing suitable sites than those sites outside the areas. The criterion for exclusion is a ground motion value beyond which the cost of construction of a safe facility increases substantially. Areas within which this ground motion may be experienced are established by a deterministic procedure. If a probabilistic analysis is used to identify suitable areas, different boundaries are obtained. If a probabilistic approach is to be utilized as one of the bases for assessing ground motion parameters for the two earthquakes, those for the higher level earthquake may be based on a reasonably long return period (in the order of 10,000 years) and those for the lower level earthquake based on 100- to 500-year return periods. However, it is not recommended that a firm ratio between the two values be used. An example area consisting of a portion of eastern Washington and Oregon is utilized to examine the relationship between ground motion values for different return periods.

● 3.4-11 Alonso, J. L. and Urbina, L., **A new microzonation technique for design purposes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 523–534.

Spectral shapes from recorded motions vary in consistent patterns depending on local soil conditions, characteristics of earthquake motions, and distances from zones of energy release. The influence of geologic and soil conditions on the damage to buildings has been recognized for quite some time. Because there may be no significant differences in seismicity within a city, one of the most important aspects in urban planning and earthquake design is to establish the variation of acceleration spectral shapes with local site conditions for different earthquakes. This paper suggests a simple technique for directly evaluating from recorded spectral shapes normalized acceleration spectrum curves and fundamental periods of soil deposits at recording stations. The technique has been used in the seismic microzoning of Merida, Mexico, and Caracas, Venezuela.

● 3.4-12 Yoshikawa, S., Iwasaki, Y. T. and Tai, M., **Microzoning of Osaka region,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 445–456.

The results of the following microzoning studies of the Osaka region are presented: tectonic conditions and active fault systems, design earthquakes, dynamic soil characteristics, earthquake response of the ground, and vulnerability to earthquake disasters.

● 3.4-13 Borcherdt, R. D., Gibbs, J. F. and Fumal, T. E., **Progress on ground motion predictions for the San Francisco Bay region, California,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 241–253.

Damage in the San Francisco Bay region from the 1906 earthquake depended strongly on the geologic character of the ground. This dependence indicates the need for seismic zoning maps of the region to outline areas where special earthquake-resistant design is necessary to reduce losses from future earthquakes. Current research is directed at defining methodologies for improved quantitative estimates of ground response on a regional scale. This research includes determination of seismic and geologic logs in 59 drill holes to a depth of 30 m.

In this paper, relations are derived between site amplifications (Amp), 1906 earthquake intensity increments, and shear-wave velocity. Geotechnical parameters, such as texture, standard penetration, and depth for sediments, and

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fracture spacing and hardness for rocks, show strong correlations with seismic velocities and provide a useful means of defining 13 units with distinct seismic characteristics. Utilizing the empirical relations, quantitative estimates of ground response at 59 sites, recently developed numerical models, and the classification of seismically distinct units on the basis of geotechnical parameters, improved quantitative estimates of variations in ground shaking can be provided on a regional scale for seismic zoning of the San Francisco Bay region. In addition, the seismic velocity relations permit extrapolation of these data to other regions.

● **3.4-14** Mihailov, V., **Seismic hazard model of Macedonia,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. I, Paper 1-09, 1978, 63–70.

The territory of Macedonia, one of the republics of SFR Yugoslavia located in the middle of the Balkan Peninsula, is one of the most active seismic zones with relatively complex tectonic and earthquake generation conditions. It is well known that the best practical presentation of earthquake loading for a given geographical region is in terms of seismic hazard maps. In this paper, by using a seismic hazard model of Macedonia, methodology for defining the seismic hazard is presented. The hazard is measured in terms of peak ground acceleration (PGA), i.e., the probability of exceeding PGA within a time period. Such a hazard map can be used for zoning purposes which, in turn, can be incorporated into building codes.

● **3.4-15** Cosentino, P., **Statistical processing of seismological data for earthquake engineering applications,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. I, Paper 1-06, 1978, 39–46.

The following methodology is presented to obtain the risk of a given peak ground acceleration or velocity in seismic areas: evaluation of frequency-magnitude parameters and relative confidence intervals, preliminary seismic zoning, earthquake risk evaluation and conservative risk estimates, evaluation of peak ground acceleration and peak ground velocity risk and conservative estimates, and final seismic zoning. Statistical processes are involved in all steps, and geological and geotechnical soil properties are considered in the last two steps.

● **3.4-16** Mortgat, C. P. and Shah, H. C., **A Bayesian model for seismic hazard mapping–a case for Algeria,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-27, 1978, 199–210.

A Bayesian model for seismic hazard mapping is presented together with an example of seismic hazard mapping of Algeria. The main features of the model are as follows. Seismic source geometry: (1) Faults are modeled by deterministically located dipping planes. Several planes (trapezoids) can be combined within a source to satisfy geometric constraints. (2) Area sources are modeled by horizontal trapezoids. (3) Line sources at a constant depth are modeled by one or a series of straight line segments. Tectonic model: A rupture area (plane sources) or a rupture length (line sources) is associated with each magnitude event. Seismicity of the sources: (1) For each source, occurrences of events independent of magnitude are assumed to follow a Poisson model. (2) Distribution of magnitudes is obtained using a Bernoulli process. (3) Subjective information is incorporated using Bayesian statistical concepts for both the above models to supplement insufficient data. Mapping parameters: Any number of mapping parameters (governed by core limitations) can be obtained in a single run. Attenuation relationship: (1) A log-normal distribution is used to take into account the uncertainty in attenuation. (2) The significant distance for attenuation purposes is chosen as the closest distance from the rupture area (length) to the site. Mapping: A whole grid of point sites is covered in one run to allow easy mapping.

● **3.4-17** Mihailov, V. and Monzon, H., **Sensitivity analysis of uncertainty in seismicity on seismic hazard estimates,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-10, 1978, 71–78.

The hazard model of Macedonia, one of the Republics of SFR Yugoslavia, is estimated to find the effect of statistical uncertainty in seismicity on seismic hazard estimation. That effect is assessed by deriving the probability distribution of peak ground accelerations. Several recent studies dealt with the questions of uncertainty in all parameters associated with the development of hazard maps and problems related to possible computed uncertainties in numerical terms. The influence of some seismic parameters upon the calculation of the seismic hazard is discussed and illustrated on graphs and seismic hazard maps.

● **3.4-18** Glass, C. E., **Application of regionalized variables to microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 509–521.

Historical sampling of earthquake ground motions has been spatially irregular and displays two contradictory aspects: (1) a random aspect characterized by unpredictable variations from point to point, and (2) a structured aspect characterized by a degree of spatial correlation. Because of these difficulties, actual ground motion records are seldom

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quantitatively used in microzonation. The theory of regionalized variables provides a method by which earthquake ground motion measurements may be used as a tool in microzonation. Using this theory, the spatial correlation of ground motion parameters is captured in a function called a variogram which displays the degree of similarity between two samples separated by some distance. Given the variogram function, the ground motion at other points may be estimated through a process called kriging. Kriging calculates a set of weights that minimizes the estimation variance at all points according to the geometry of the problem and characteristics of the ground motion. The technique is demonstrated using intensity data from the 1872 northwest Pacific earthquake. Once the spatial distribution of surface motions is estimated for each event affecting the site, conventional techniques must be applied in the time domain to calculate the earthquake hazard.

● 3.4-19 Mandrescu, N., **The Vrancea earthquake of March 4, 1977 and the seismic microzonation of Bucharest,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 399–411.

The 7.2 magnitude earthquake that occurred in the Vrancea region on Mar. 4, 1977, caused extensive damage throughout the country, particularly in Bucharest, Craiova, Zimnicea, Valenii de Munte, Ploiesti and Cimpina. In Bucharest, the greatest damage occurred in the center of the city, where 32 older buildings of 8–12 stories collapsed and many other buildings were seriously damaged. Many small dwellings and nearly all modern apartment buildings were not damaged at all.

To estimate the intensity of the seismic shock in Bucharest, about one thousand masonry, reinforced concrete frame, and large panel buildings, distributed throughout the area, were examined. Taken into account were soil and subsoil characteristics, type of structure, height, age and state of the buildings. Territorial repartition of damages for each class of buildings is plotted on the maps and has been used for a new seismic microzonation map of Bucharest. The map has been compared with a similar map prepared after the Nov. 10, 1940, earthquake and with the microzonation map prepared in 1973 according to the Medvedev method. A relationship was pointed out between the spectral composition of the Vrancea intermediate earthquake of Mar. 4, 1977, and selective damaging of the tall buildings in the Bucharest area.

● 3.4-20 Ploessel, M. R., **High-resolution geophysical surveys, a technique for microzonation of the continental shelf,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 647–655.

A high-resolution geophysical survey is a necessary component of the studies for microzonation of areas on the continental shelf. The shallow geology of the continental shelves cannot be adequately understood without high-resolution seismic data. High-resolution survey instruments include side-scan sonar, Fathometer, tuned transducers, boomers, and sparkers. These instruments provide a map view of the seafloor, as well as subbottom data along the line of survey. Tuned transducers and boomers provide information to depths of 100 to 500 ft below the seafloor and can resolve individual layers 1 to 3 ft thick. Faults with as little as 1 to 2 ft of throw (vertical offset) can be identified on the records. Sparkers provide data to depths in excess of 3000 ft below the seafloor, but can only resolve individual layers about 25 ft apart. However, faults with as little as 10 ft of throw can be identified from sparker records. High-resolution geophysical data, particularly from boomer systems, also provide an indication of the characteristics of seafloor materials. Although geophysical data are not a substitute for sampling of materials, very soft, unconsolidated sediments commonly can be distinguished from denser sediments and from rocks. High-resolution geophysical data have already been obtained for large portions of the United States continental shelves.

● 3.4-21 Adeli, H., Nemat-Nasser, S. and Rowshandel, B., **A probabilistic estimate of peak ground acceleration in Iran,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-18, 1978, 129–134.

The objective of this study is to estimate, probabilistically, future earthquake occurrences in Iran. The analysis is based on earthquakes recorded during the present century; these data have been gathered from different sources and have been corrected whenever possible. The Poisson model is used for the development of cumulative distribution functions for some major cities and for seismic hazard maps. A few examples are given here for illustration.

● 3.4-22 Campbell, K. W., **Empirical synthesis of seismic velocity profiles from geotechnical data,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 1063–1075.

A method has been developed by which a shear-wave velocity profile beneath a site may be synthesized from such readily available geotechnical information as geological maps, water well logs, soil boring logs, and water table depths. The method is based on empirical correlations among shear-wave velocity, depth, and a geotechnical classification system developed from 109 in-situ measurements conducted throughout the southern California area since 1971. Synthetic velocity profiles developed in this way may be used for microzonation purposes and for other

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applications where seismic velocity measurements are not feasible.

● 3.4-23 Idriss, I. M., Cluff, L. S. and Patwardhan, A. S., **Microzonation of offshore areas—an overview,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1281–1290.

In principle, methods of microzonation of offshore areas are similar to those used for onshore areas. However, the differences in the range and characteristics of parameters used in defining the zonation criteria for comparable levels of safety or acceptable risk may yield zonation maps of a different character. These parameters include seismicity, earthquake recurrence intervals, subsurface conditions, and structural characteristics. Simplified subregional tectonic models may be used for seismic zonation, and the resulting zones may be somewhat larger when offshore than when on land. To improve the accuracy of the results, it is necessary to investigate and collect data in offshore environments. Structural characteristics of major offshore structures, such as platforms, suggest that zonation be based on such ground motion parameters as peak velocity, spectral velocity, or spectral displacement, rather than on peak acceleration. It is advantageous to base the zonation on an evaluation of seismic exposure, and to supplement the seismic exposure evaluations with representative subsurface data.

● 3.4-24 Patwardhan, A. S., **Factors influencing seismic exposure evaluation for offshore areas,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1291–1305.

Seismic exposure evaluation is an essential step in seismic zonation, evaluation of seismically induced hazards, and risk-based design of offshore structures. Application of the results of a seismic exposure evaluation is based on calculated values of ground motion parameters which, in turn, are influenced by input parameters and the exposure evaluation model. The relative influence of various factors is discussed by examining seismic exposure in the Gulf of Alaska. Major influencing factors include the source characterization, attenuation characteristics, and the exposure evaluation procedure. By dividing the overall seismic exposure values into the contributions of different sources and factors, the seismic exposure evaluation becomes more specific and valuable.

● 3.4-25 Fischer, J. A. and Spiker, C. T., **Preliminary microzonation of the Baltimore Canyon lease area,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1329–1339.

Deterministic analysis of known and postulated structures under the Atlantic continental shelf and tentative correlations with historical seismicity suggest conservative design levels of modified Mercalli intensities of VI and VII for strength and ductility, respectively. Appropriate correlations show design levels of acceleration of 5 and 10% of gravity upon the generally good subbottom soils in the area. Expected variability of surficial (foundation) sediments necessitates future site-specific analysis to confirm the near-surface effects on the character of the input vibratory ground motion to be used in anchoring design response spectra.

● 3.4-26 Mortgat, C. P. and Shah, H. C., **A Bayesian approach to seismic hazard mapping; development of stable design parameters,** *28,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Mar. 1978, 233.

The first part of the study concentrates on seismic hazard mapping which can best be defined as the exposure to seismic loading at a given location. This exposure is expressed in terms of an effect and the probability of its occurrence. The study's second part examines stable design parameters and provides a statistical and probabilistic view of the response of structures to earthquake excitation. Attention is focused on response parameters which have a direct engineering value.

● 3.4-27 Murakami, S. and Midorikawa, K., **Land use technique for microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 547–558.

This paper examines microzonation techniques usable by administrators to control population density, building utility, and location of urban facilities. Its purposes are to develop techniques to research soil conditions, to analyze seismic intensity, and to aid in land use planning.

● 3.4-28 Kuroiwa, J. *et al.*, **Microzonation methods and techniques used in Peru,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 341–352.

After the Peruvian earthquake of 1970 (official death toll: 67,000), an interdisciplinary group was formed to carry out microzonation studies in the cities and towns destroyed by the earthquake. At the time this paper was written, studies had been completed in eight cities, including many on-site investigations for new industry and harbor locations and for the Peru Nuclear Center. The primary

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disciplines of the group included seismology, geology, soil mechanics, soil dynamics, and earthquake engineering. The methods used in evaluating soil dynamics were based mainly on those developed in the last six years at the Univ. of California, Berkeley, and the Univ. of Tokyo, but were modified to suit local conditions. Because Peru consists of a very arid coastal region, the high Andes region, and the Amazon Jungle, it was necessary to pay special attention to external geodynamics in addition to conducting the usual site and seismic investigations.

● 3.4-29 Shima, E., **Seismic microzoning map of Tokyo,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 433–443.

Geological sections delineated on a map of Tokyo published by the Tokyo Metropolitan Government were converted into shear wave velocity sections using a large amount of shear wave velocity data. An amplification study employing multiple reflection theory was then carried out at more than 800 points. Since the investigators could not find a common base rock throughout the area, it was assumed that the deepest formation at the site was the base rock. It was found that there is a linear relationship between the square roots of powers of responses and the ratios between the shear wave velocities of base rocks assigned at the sites and those of surface layers. The thickness of the subsoil had little effect in deriving the above results. Thus, the relative magnitude of vibration at any site throughout the area could be obtained without information about the actual base rock.

● 3.4-30 Bune, V. I. and Nersesov, I. L., **An improved map of seismic zoning of the USSR territory,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-15, 1978, 107–114.

This paper discusses the 1978 seismic zoning maps of the U.S.S.R. For the first time, these maps delineate seismic source zones and evaluate probable earthquake recurrence times.

● 3.4-31 Roussopoulos, A. A., **Seismic zoning and nuclear power plants,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. III, 809–822. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Seismic zoning and strong-motion records are discussed from the standpoint of the May 6, 1976, Friuli earthquake, and strong-motion data recorded in Greece are presented. The analysis of the records from Greece gives useful information concerning the ground accelerations, velocities, and spectral values and provides the basis for seismic microzoning investigations which are of primary importance for the evaluation of seismic risk. Discussed in the final part of the paper are the importance of using seismic design criteria in the siting of nuclear power plants and the need for more accurate seismic zoning maps that take into account strong-motion data and seismic microzoning techniques.

● 3.4-32 Taga, N., Ando, T. and Miyazaki, T., **Earthquake damage potential of wooden structures and grounds in Nagoya by seismic microzoning** (in Japanese), *Transactions of the Architectural Institute of Japan,* 272, Oct. 1978, 63–73.

The dynamic behavior of wooden structures and soil layers in Nagoya is estimated by considering the seismicity, soil properties, and the composition and vibrational characteristics of the structures. Future seismic conditions are predicted for a nearby earthquake and a distant earthquake on the basis of data of past earthquakes that occurred in the Chubu district. The ground in the Nagoya area is idealized as horizontal soil layers. The depths and soil properties of the layers are determined by means of deep-well borings and seismic wave tests. The fundamental periods and critical damping ratios of the structures are considered. The dynamic responses of structures on 173 city sites are analyzed and microzoned according to the damage level. A map of the distribution of the predominant periods of the ground surface is developed by use of microtremor measurements. Seismic damage potential is compared with seismicity, ground conditions, and structural properties.

● 3.4-33 Martinez, A. and Romani, F., **Geotechnical model for seismic microzonation,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/22, 1977, 293–296.

This paper proposes a model that determines, by means of a multidisciplinary study, local geotechnical parameters that are necessary for efficient planning and the reduction of earthquake damage to structures. Such geotechnical data and other data of interest should be compiled into seismic microzoning maps. A set of microzoning maps for Lima, Peru, are presented.

3.4-34 Bune, V. I., **The new elements on the map of seismic zoning,** *Bollettino di Geofisica,* XX, 78, June 1978, 102–109.

The zones of probable generation of earthquake sources differentiated according to their depths and M_{max}, as well as quantitative assessments of the probability of shaking, are new elements on the map of seismic zoning of

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the U.S.S.R. An example of the map with the new elements is presented.

3.4-35 Drakopoulos, J. C., **The importance of a complete microzonation procedure and reliability of the existing methods,** *Bollettino di Geofisica,* **XX,** *79,* Sept. 1978, 235-250.

The term microzonation suggests the study of the difference in response at sites which share the same seismic exposure. The frequency components of the motions at different sites and the form of the response spectra may be influenced by the nature of soil conditions underlying the site, i.e., a change in a consistent fashion depending on the rigidity of the soil formations. The most frequently used microzonation methods are discussed in this paper. A microzonation procedure is in itself a systems problem in which a large variety of information must be combined to achieve an optimum solution to the earthquake problem. Data must be received from seismological, geological, soil engineering, geophysical, and geodetic detailed studies. The application at a site of all existing techniques (Medvedev, microtremor, soil amplification spectra) and the comparison between them gives the best results. It is important to realize that, when a strong earthquake occurs, the resulting response and damage constitute the true microzonation.

3.4-36 Perkins, D. M., **Acceleration hazard map sensitivity to input seismic parameters,** *Bollettino di Geofisica,* **XX,** *78,* June 1978, 188-196.

Among the seismicity parameters of a source region, the seismic rate itself has the least effect on the value of acceleration for a given return period which is obtained by a probabilistic ground motion hazard analysis. Somewhat more important is the b-value. However, the maximum magnitude often assumes a predominant importance, since for regions with historically observed low maximum magnitudes, the results of the hazard analysis change dramatically with small changes in the maximum magnitude. The curves of this study also offer a means for anticipating the results of a hazard analysis for a source region, given its seismicity parameters.

3.4-37 Perkins, D. M., **Prospects for the use of geologic data in United States hazard maps,** *Bollettino di Geofisica,* **XX,** *78,* June 1978, 180-187.

Development of the Algermissen and Perkins acceleration hazard maps has resulted in the U.S. Geological Survey refocusing its effort in areas applicable to hazard mapping. This paper points out that studies in the western United States are more likely to yield near-term data for reevaluating hazard on a regional scale and that geological studies should be used to establish long-term seismic parameters when appropriate.

3.4-38 Perkins, D. M., **Status and prospects for national seismic hazard and zoning maps in the United States,** *Bollettino di Geofisica,* **XX,** *78,* June 1978, 165-179.

The basis for the construction of the Algermissen and Perkins U.S. probabilistic acceleration hazard map is summarized. Extrapolation from the map values to values for other return periods is outlined using either a simple rule or a set of curves. The map has led to a simplified pair of maps for acceleration and velocities to be used for a proposed national earthquake building code. The same underlying seismicity data and technique are intended to be used to construct U.S. maps for response velocity, modified Mercalli site intensity, and, possibly, bracketed duration.

● 3.4-39 Hsiung, Y. M., Bolt, B. A. and Penzien, J., **Studies of strong ground motion in Taiwan,** *UCB/EERC-78/26,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1978, 114.

In Part I of this report, a general analysis is made of the characteristics of three strong ground motion records obtained from a moderate earthquake near Wufeng, on Apr. 14, 1976. Both time and frequency domain techniques are used. The intensity function has a single peak shape, which suggests that the fault mechanism is simple. Using an intensity function of this shape, the general pattern of the ground motion is simulated. A comparison of these simulated motions with the recorded ground motions shows similar characteristics. The frequency domain analysis indicates that the predominant frequency is about 2.5 Hz. The interpretation of the fault-plane solution, which appears to give the best explanation of the strong ground motion records, is that the fault is a left-lateral thrust with N41°E strike and 36°SE dip. Although this interpretation is different from that of CERC obtained from sensitive seismographs, it agrees well with almost all the strong-motion records.

In part II of this report, the problem of risk maps is examined using the distribution of seismic intensity both in time and space in Taiwan. In this study, instead of the Poisson distribution for earthquake occurrence, a modified hazard distribution is adopted. This distribution allows a dependence between successive earthquakes. Hazard contour maps have been drawn using this method for 13 cases. These are compared with various risk map estimates, by other authors, having the same general tendencies.

3.5 Influence of Geology and Soils on Ground Motion

● 3.5-1 Hays, W. W. *et al.,* **Preliminary ground response maps for the Salt Lake City, Utah, area,** *Proceedings of the Second International Conference on Microzonation for Safer*

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

Construction—Research and Application, National Science Foundation *et al.,* San Francisco, Vol I, 1978, 497–508.

Preliminary maps of relative ground response were constructed for the Salt Lake City area using nuclear-explosion ground motion data recorded at 27 sites. These maps demonstrate that large differences in ground response relative to rock occur throughout the area at sites underlain by unconsolidated water-saturated materials. These maps provide a basis for evaluating the risk from ground shaking in the Salt Lake City area.

● 3.5-2 Castellani, A. *et al.,* **Seismic waves modification at hilly sites,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-34, 1978, 259–266.

The influence of local topography on earthquake ground motion is considered for some hilly sites, during the seismic activity in Friuli, Italy, in 1976. The suggested conclusion refers mainly to the records collected by the Ist. per la Geofisica della Litosfera at Buia, and to a few others previously described. The objective of this paper is the "deconvolution" of the acceleration records, in order to translate them into standard topography records, suitable for mapping the attenuation laws of the region and useful in seismic zoning.

● 3.5-3 Sabina, F. J., Herrera, I. and England, R., **Theory of connectivity: applications to scattering of seismic waves. I. SH wave motion,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 813–824.

This paper presents a method based on the theory of connectivity to solve numerically the problem of scattering of seismic waves by bounded obstacles of arbitrary shape in an infinite domain, such as a canyon in a halfspace. This method reduces the dimension of the problem by one but avoids the introduction of singular integral equations. The results obtained are compared with some known exact solutions for SH-wave motion, producing very good agreement. Results for an irregularly shaped obstacle are also given. It is observed that, for a trench with vertical walls, local amplification factors can significantly exceed 100%.

● 3.5-4 Goto, N., Ohta, Y. and Kagami, H., **Deep shear wave velocity measurement for evaluation of 1-10 sec seismic input motions,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 793–800.

Deep shear wave velocity loggings at two sites in the Tokyo area have been carried out down to 3500 m and 2300 m using earthquake observation wells. The purpose of these surveys is to determine the effects of deep sites on earthquake ground motions of 1-10 sec periods. Shear waves are produced by means of ordinary small explosions and by a specially designed SH-wave generator. A set of three-component seismometers was installed in a capsule clamped to the borehole wall. Measurements were conducted at intervals of 100-500 m. The velocity structures agree with the known data, such as sonic logs, density distributions, geologic sections, and so on. Rough estimations of the amplification between the ground surface and bedrock are made, and the importance of shear-wave measurement for thick soil deposits is stressed.

● 3.5-5 Oweis, I. S., **The relevancy of one dimensional shear models in predicting surface acceleration,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 777–792.

A simple shear beam model was established based on detailed analyses of cases covering various soil profiles from 15 sites. The profiles were excited by rock motions of varying intensities and frequencies. The results were compared with recorded data. It is concluded that (1) amplification occurs for low-intensity rock motions in virtually all soil profiles; (2) for high-intensity rock motion, soils tend to attenuate rock motion; and (3) profiles with large fundamental periods tend to attenuate rock motion. Such profiles may be soft profiles or deep dense profiles. It is shown that these observations are in qualitative agreement with observational data but that, quantitatively, discrepancies may exist, increasing in significance with increasing stiffness of the profiles.

● 3.5-6 Shakal, A. F. and Toksoz, M. N., **Analysis of source and medium effects on strong motion observations,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 717–728.

The influence of the medium and source on recorded strong ground motion is studied by analyzing accelerograms and by using theoretical modeling techniques. The causes of the variations of ground motion at nearby sites are investigated by calculating the spectra, spectral ratio, and coherency for records from the San Fernando and Kern County, California, earthquakes. The results show that the ground motion is coherent at low frequencies but that coherency drops off at higher frequencies (between 1 and 10 Hz), depending on station spacing and site characteristics. The Pasadena and Lake Hughes area strong-motion records from the San Fernando earthquake are reexamined to investigate the effects of local geology on the amplification of ground motion and the frequency dependence of this amplification. At the low frequencies in the pass band

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of the Wood-Anderson instrument, the strong motion shows the effects of sediment layering similar to the effects seen by Gutenberg. At the higher frequencies, to which the acceleration is most sensitive, the shallow sedimentary layers have the greatest effect. Theoretical seismograms are calculated for a finite propagating source, and the variation of these with azimuth is demonstrated.

● 3.5-7 Duke, C. M. and Liang, G. C., **Site effects from Fourier transforms**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 1025-1036.

The San Fernando, Kern County, and Managua earthquakes yielded a substantial number of strong-motion accelerograms. These records have been found to express the effects of local site conditions when the latter are available in terms of shear wave velocities and depths. Given these subsurface properties in sufficient detail, the respective subsurface characteristics may be expressed in the frequency domain using Fourier transforms. Multiple records are available from all three of the earthquakes cited. This permits the optimization of the subsurface mathematical models between bedrock and the ground surface. The product of the optimization is an instrumental subsurface model whose precision exceeds that of the initial models that were based only on exploratory data.

● 3.5-8 Sanchez-Sesma, F. J., **Ground motion amplification due to canyons of arbitrary shape**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 729-738.

A method is presented for computing the scattering and diffraction of plane seismic waves caused by a canyon of arbitrary shape. The problem is formulated using Fredholm integral equations of the first kind in which the integration path is defined outside the boundary, thus producing kernels which are regular. A class of discretization schemes using line source solutions is employed. Boundary conditions are satisfied in the least-squares sense. Semi-analytic line-source solutions are used for incident P or SV waves. Numerical results are presented for amplification spectra for semicircular canyons. Extensions and possible applications are discussed.

● 3.5-9 Rogers, A. M. and Hays, W. W., **Preliminary evaluation of site transfer functions developed from earthquakes and nuclear explosions**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 753-763.

Ground motion produced by the 1971 San Fernando earthquake was compared to that accompanying Nevada Test Site nuclear explosions, using recordings of both events at several common stations in the San Fernando Valley-Pasadena area of California. Similar trends in ground response were observed for both sources. Those differences in the nuclear and earthquake ratios that were observed are tentatively explained by changes in wave propagation at the rock sites due to the proximity of the earthquake source relative to the nuclear source. The known dispersion in such observations, however, would also account for significant portions of the observed variations.

● 3.5-10 Sadigh, K., Power, M. S. and Youngs, R. R., **Peak horizontal and vertical accelerations, velocities, and displacements on deep soil sites during moderately strong earthquakes**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 801-811.

This paper examines the relationships for horizontal and vertical peak ground motion parameters for moderately strong earthquakes in the western United States using recordings obtained on deep soil sites. Attenuation relationships for peak ground motion parameters were derived by linear regression analyses using data from recordings obtained during earthquakes in the magnitude (M_L) range 6.3-6.5.

The vertical peak acceleration was found to attenuate at a faster rate than the horizontal peak acceleration. Horizontal and vertical velocities were found to attenuate at about the same rate; similarly, the rate of attenuation was about the same for horizontal and vertical displacements. For both horizontal and vertical components, the ratios of peak velocity to peak acceleration, v/a, were found to increase with distance, while the ratios of ad/v^2 were found to decrease slowly with distance.

● 3.5-11 Crouse, C. B. and Turner, B. E., **Analysis of ground motion spectra**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 1117-1132.

The purpose of this investigation was to study the character of the response spectra of earthquake ground motions recorded in the western United States. Linear regression analyses of spectral ordinates with source-site distance as the independent variable were performed on data sets limited to small magnitude ranges, specific local soil conditions, and component direction. The results indicate that higher frequency spectral differences for records having different local soil conditions may be partially due to soil-structure interaction. The possibility of this coupling

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was suggested by Crouse, and studies of additional data lend support to this hypothesis. Attenuation rates were also noted to generally decrease with increased period for most data sets, and were generally greater for rock than for soil sites. The standard errors from these regression analyses were less than those obtained by Trifunac and Anderson. The attenuation study also indicated that the ratio of the vertical to horizontal spectra may be independent of distance.

● 3.5-12 Werner, S. D. and Ts'ao, H. S., **Effect of local site conditions on spectral amplification factors,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 1077-1088.

The effects of local site conditions on spectral amplification factors (SAFs) are studied to determine the sensitivity of these effects to the method of normalizing the spectral amplitudes and to provide comparisons with the U.S. Nuclear Regulatory Guide (RG) 1.60 SAFs, which are widely used in current design practice. The study is carried out by first grouping a large ensemble of horizontal and vertical free-field records into one of the three site classifications—deep soil, intermediate soil, and rock—using results from recent geotechnical investigations at accelerograph sites throughout the western United States. Then, for each site classification, statistical analyses of normalized spectral amplitudes at 91 discrete frequencies are used to develop mean and 84th percentile SAF versus frequency curves for horizontal and vertical motions. The results show that the effects of local site conditions on the SAFs differ for high-, intermediate-, and low-frequency spectral amplitudes normalized according to peak acceleration, peak velocity, and peak displacement, respectively. Also, the RG 1.60 horizontal SAFs are seen to be most applicable to horizontal motions on the deep-soil and intermediate-soil sites, and the vertical SAFs provide extremely conservative representations of vertical motions, regardless of site conditions.

● 3.5-13 Tucker, B. *et al.*, **A preliminary report on a study of the seismic response of three sediment-filled valleys in the Garm region of the USSR,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 1051-1062.

In 1976 and 1977, experiments were conducted to determine the response to earthquake motions of three sediment-filled valleys in the Garm region of the U.S.S.R. Twelve intermediate-period seismometers were deployed in various profiles across the valleys, with another three-component set of seismometers on the rock bordering and underlying each valley. Recording was direct-digital using four four-channel portable digital recorders. The experimental setting and equipment are briefly described, and some preliminary results of the responses of the valleys to steeply incident P waves are presented.

● 3.5-14 Lam, I., Tsai, C.-F. and Martin, G. R., **Determination of site dependent spectra using non linear analysis,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 1089-1104.

The significance of local site response of soft soils in modifying earthquake ground motion characteristics is examined using a nonlinear one-dimensional dynamic response analysis. The nonlinear explicit finite difference program (DETRAN) used for these analyses is based on a physically motivated viscous elastoplastic soil model incorporating a failure criterion, degradation characteristics, and an energy-transmitting boundary. The boundary provides a method of ground response analysis without the need to define bedrock at a finite depth. The procedure is illustrated with reference to idealized soft soil sites underlain by more competent firm ground. Two representative firm ground earthquake acceleration time histories were defined by an outcrop surface motion, and the response of the examined site to ground motions was scaled to give peak outcrop accelerations of 0.05 g and 0.45 g. Comparisons are made with equivalent linear SHAKE analyses, and the significance of incorporating soil yield into acceleration levels and spectral shapes is demonstrated. Spectral shapes are compared with an average smoothed spectrum available in the literature, and significant changes in shape with acceleration level are noted.

● 3.5-15 Donovan, N. C., **Soil & geologic effects on site response,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 55-80.

During the past decade, optimism has been replaced by a growing degree of caution over the use of one-dimensional site response analyses as a means of quantitatively developing site-specific design parameters. The ability to demonstrate site effects by analytic means was a significant advance, but it also led to neglect of other equally significant parameters. The ability to model a special case and the weaknesses of the model are demonstrated in this paper by a comparison of computed and recorded motions. Much attention has been given in the literature to the extremes of strong-motion recording. A more rational approach is described in which the mean value of data sets is used in conjunction with the distribution of data values about that mean. Procedures for developing site-specific design criteria, based on mean values

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with the use of a known measure of conservatism, are described.

● **3.5-16** Cvijanovic, D. and Mihailov, V., **Correlation between the seismological data and the accelerograms obtained in Yugoslavia,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-05, 1978, 33–37.

By the beginning of 1972 in the territory of SFR Yugoslavia a network of accelerographs was installed. From 1972 to 1977 the instruments registered 61 earthquakes with magnitudes 2.5 to 7.2 at various hypocentral distances. One hundred twenty-five accelerograms were obtained with registrations on all three components: NS, EW and V. In the paper, a relationship between the main characteristics of earthquakes (magnitude M and intensity I_m) and maximum acceleration values a_{max} of soil particle oscillation is considered.

● **3.5-17** Moriwaki, Y. and Doyle, E. H., **Site effects on microzonation in offshore areas,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1433–1445.

Earthquake ground motions at three selected sites in typical offshore environments are compared using a combination of empirical and analytical procedures. The selected sites consist of rock, soft clay, or stiff clay. Ground response analyses are conducted using a one-dimensional procedure that incorporates the nonlinear stress-strain behavior of the clay and accounts for modulus degradation during cyclic loading. The analytical results are compared to available empirical relationships to assess the trends obtained by either procedure. The results can be used to provide a reasonable means for establishing general seismic zones or for conducting site-specific studies.

● **3.5-18** Ohta, Y. *et al.,* **Observation of 1- to 5-second microtremors and their application to earthquake engineering. Part I: comparison with long-period accelerations at the Tokachi-oki earthquake of 1968,** *Bulletin of the Seismological Society of America,* **68**, *3*, June 1978, 767–779.

A study of possible amplification characteristics of strong motions resulting from deeply situated deposits was made by observing 1- to 5-sec microtremors. During the Tokachi-oki earthquake of 1968 ($M = 7.9$), several accelerograms were obtained, among which some are dominant but others are not significant for periods longer than 1 sec. To understand whether these differences result from source and path effects or site conditions is important for estimating seismic input motions to highrise buildings. Long-period microtremors were observed to pursue this problem.

Observations were carried out in three cities where typical acceleration records had been obtained using a specially designed instrument for recording microtremors with periods ranging from 0.5 to 6 sec. Each observation line was chosen so as to traverse the accelerograph site along which a remarkable geological change of the underground structure is expected—from the outcrop of bedrock to the alluvial deposit, for example. By comparing the obtained spectra and their peaks with those derived from the strong-motion records, it was concluded that their predominancy and predominant period in the long-period range are clearly the result of deeply situated deposits. Procedures for observing and analyzing long-period microtremors are proposed, with attention given to overcoming the defects in the technique used for short-period microtremors.

● **3.5-19** Asten, M. W., **Geological control on the three-component spectra of Rayleigh-wave microseisms,** *Bulletin of the Seismological Society of America,* **68**, *6*, Dec. 1978, 1623–1636.

Microseisms in the band of 1 to 15 Hz propagate principally as multi-mode Rayleigh waves. Comparison of some previously published spectra from sites over unconsolidated sediments with theoretical Rayleigh-wave dispersion curves shows a high correlation between observed broad spectral maxima and theoretical group-velocity minima. This gives practical support to a recent prediction of this relationship. Comparison of three-component spectra with theoretical Rayleigh-wave dispersion curves and particle motion figures shows that fine structure in the observed spectra can be correlated with changes in the particle motion figures for different Rayleigh modes. Thus both broad and fine spectral features are affected by local geology and can give useful control when inverting microseism data to obtain a seismic model. The Rayleigh wave nature of microseisms implies that direct interpretation of spectra in terms of body-wave seismic resonances of the earth is incorrect. However, since an approximate correspondence exists between theoretical group velocity minima and body-wave resonant frequencies, some spectral maxima do occur near such frequencies.

● **3.5-20** Romstad, K. M., Bruce, J. and Hutchinson, J. R., **Site dependent earthquake motions,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT11*, Proc. Paper 14173, Nov. 1978, 1389–1400.

A statistical method is developed for modeling time-varying earthquake-induced acceleration levels which will produce smooth response spectra of the desired shape and amplitude levels. Specific records are derived to simulate a mean spectrum developed from historically recorded rock motions and also for the Atomic Energy Commission's regulatory guide spectrum. The synthetic rock motion is

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then used as the input motion for a number of site conditions simulating stiff, deep, cohesionless and soft-to-medium clay and sand sites. The computer program SHAKE is used. The results are compared to mean spectra for similar sites derived from historically recorded motions and are shown to provide reasonable engineering estimates of site motions.

● 3.5-21 Aleksovski, D., **Geophysical parameters for defining dynamic geotechnical models**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-03, 1978, 15-22.

Seismic ground motion is influenced by the nature of the soil, particularly by the nature of the surface layer. For this reason, to determine the dynamic response of soil, it is important to have data on the density, thickness, damping, and shear wave velocity characteristics of each layer. These parameters can be determined from data obtained from geological borehole investigations, experimental geophysical measurements of elastic seismic waves, and from measurements of the predominant periods of microtremors.

● 3.5-22 Trifunac, M. D. and Westermo, B. D., **Dependence of the duration of strong earthquake ground motion on magnitude, epicentral distance, geological conditions at the recording station and frequency of motion** (in English and Serbian), *59*, Inst. of Earthquake Engineering and Engineering Seismology, Univ. of Skopje, Yugoslavia, June 1978, 26.

A new definition of the duration of strong earthquake ground motion is presented. It is based on the mean-square integral of motion and employs the derivative of the smoothed integral of the time function squared to compute the principal contribution to the ground motion duration. This definition is related directly to the seismic energy recorded at a point and to the response spectrum amplitudes of a linear viscously damped oscillator. Correlations are presented which characterize the duration of strong ground motion in terms of earthquake magnitude, epicentral distance, geological environment of the recording stations, and the frequency content of recorded motions.

● 3.5-23 Dobry, R., Idriss, I. M. and Ng, E., **Duration characteristics of horizontal components of strong-motion earthquake records**, *Bulletin of the Seismological Society of America*, 68, 5, Oct. 1978, 1487-1520.

The duration characteristics of the horizontal components of strong ground motion records obtained in the western U.S. were examined for engineering applications. A total of 84 accelerograms were used in the study, corresponding to a range of earthquake magnitudes, M, between 4.7 and 7.6, to distances to the source between 0.1 and 130 km, and to local subsurface conditions ranging from rock to soft clay. The definition of significant duration, D (sec), used was the time needed to build up between 5 and 95 percent of the total Arias intensity of the record. For rock sites, a consistent correlation was obtained between D and M. Values of D at soil sites show a much larger scatter, with the duration on rock being a lower bound.

Detailed analyses were conducted of the accelerograms and their associated Husid plots. It was found that a main parameter controlling the duration of strong ground motion was the total duration of rupture at the fault, d. Rock records are dominated by a strong part, having a duration, Δ, which is essentially a straight line in the Husid plot, and which is Δ less than or nearly equal to D. This strong part coincides approximately with the arrivals of S waves which followed a direct path between source and station (direct S waves). The values of both Δ and D are mainly controlled by the duration of rupture at the fault, d, for M less than or nearly equal to 7. Many soil records have, in addition to the strong part, another part which is moderately strong, has longer periods and appears after the direct S wave arrives. This additional part is responsible for the increased values of D observed for soil, and also for the curved shape of the Husid plot observed in many soil records. This part also contributes significantly to the observed richer content of long periods in soil records, reported by several authors. Some evidence suggests this part of the record may be mostly associated with the amplification by the soil of indirect, multipath body-wave arrivals, and with surface-wave effects.

● 3.5-24 Yamamizu, F. and Goto, N., **Direct measurement of seismic wave velocities in deep soil deposits**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 42, Nov. 1978, 329-336.

To determine the response characteristics of deep soil deposits during an earthquake, the seismic wave velocities of the deposits to the depth of several kilometers are required. The authors used the downhole method to measure the velocity of P and S waves down to depths of 3510 m and 2300 m at two sites in Japan. S waves were generated by small explosions in subsidiary shallow boreholes and by an SH-wave generator. The experiment revealed that the medium basically consisted of three layers. The basement is a pre-Tertiary layer, and two layers above this basement are Pleistocene and Miocene layers. Based on this structure, the response characteristics were computed. The amplification of seismic waves was found to be significant for the long-period range.

● 3.5-25 Miyajima, N., Asaoka, H. and Aono, Y., **Earthquake characteristics in adjacent grounds with different ground structures** (in Japanese), *Proceedings of the Fifth*

Japan Earthquake Engineering Symposium-1978, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 25, Nov. 1978, 193–200.

The earthquake response analysis of extended structures, such as pipelines and submerged tunnels, requires an investigation of the amplification characteristics of the ground motion at several points along such a structure. Simultaneous ground motion observation has been carried out at Chiba Prefecture at two points approximately 4 km apart. At one point, Station A, a soft surface layer 23 m thick exists; its N-value is below 8. At the other point, Station B, there is no evidence of a soft surface layer. The difference in elevation between the two stations is 30 m; Station B is located at the higher point. At both stations, where N-values greater than 50 are found, the ground is considered to be continuous strata. At Station A, accelerometers are installed 15 m, 35 m, and 80 m below the surface. These accelerometers record three-component accelerations. At Station B, accelerometers have been placed 1 m, 12 m, and 30 m below the surface and record two horizontal accelerations at each level.

Four earthquakes have been observed since June 1976. Two were near-field earthquakes, and two were medium- to far-field earthquakes. Two earthquakes, one of each type, are analyzed. Typical acceleration records are presented. At both stations, most of the Fourier acceleration spectra are predominantly in the lower frequency range for the medium- to far-field earthquake and in the higher frequency range for the near-field earthquake. However, the spectra for the soft surface strata and the stiff stratum beneath the surface are not the same. The horizontal components are amplified in the soft surface layer but are only slightly amplified in the stiff stratum. Conversely, prominent amplification characteristics for the vertical component are not discernible in the surface stratum but are discernible in the stiff stratum. It is postulated that this characteristic is caused by a 4-m thick stratum that is softer than the upper and lower strata.

● **3.5-26** Sawada, Y. *et al.*, **Accelerograms of the Izu Oshima Kinkai aftershocks recorded on bedrock near origins** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 30, Nov. 1978, 233–240.

The Izu Oshima Kinkai, Japan, earthquake ($M = 7$) occurred on Jan. 14, 1978. Many foreshocks and aftershocks accompanied the earthquake. Numerous acceleration records were obtained at two stations installed on andesite near the earthquake origin. This data, recorded with long-term tape recorders, covers a wide range of magnitudes ($1.2 \leq M \leq 5.8$) and hypocentral distances (about 10 km for $M \leq 3.5$ and 30 km for $3.0 \leq M \leq 5.8$). From the observational results, the characteristics of seismic shaking on the bedrock were obtained.

Peak accelerations and peak velocities of seismic waves observed at a hypocentral distance of 30 km are clearly dependent on the range of magnitude; the rates of change of peak accelerations and peak velocities with magnitude coincide with the results of other Japanese researchers. Peak amplitudes at the shorter distance of 10 km, however, show a significant scattering in the magnitude range $M \leq 3.5$. It appears that the duration of the main phase and the peak amplitude frequency of the accelerograms can be expressed as a function of magnitude. The averaged Fourier spectra in each magnitude range indicate that the spectral peak increases in the high-frequency part as the magnitude decreases. Peak accelerations at a hypocentral distance of 10 km increase significantly with a magnitude between $1.2 \leq M \leq 5.0$).

● **3.5-27** Nagahashi, S., **Response spectra of earthquake ground motions expected in Tokyo** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 2, Nov. 1978, 9–16.

This paper proposes an empirical formula to calculate velocity response spectra of bedrock seismic motion. The response spectra of strong ground motions resulting from several earthquakes which are expected to occur in the Tokyo area are evaluated.

● **3.5-28** Kitagawa, Y. and Ozaki, M., **Study on regional characteristics of maximum earthquake motions in Japan,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 1, Nov. 1978, 1–8.

This paper calculates expected intensities of future earthquakes at the base rock in and around Japan by using Gumble's theory of extremes (Gumble's second asymptotic distribution). It also calculates the regional distribution of deep soil-layer characteristics for a fairly large area in the period range 2.0 to 6.0 sec., using seismic data obtained from strong-motion seismographs published by the Japan Meteorological Agency.

● **3.5-29** Kawashima, K. and Takagi, Y., **Seismic behavior of subsurface ground based on measured underground motions** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 16, Nov. 1978, 121–128.

This paper discusses the dynamic behavior of subsurface soil and rock layers on the basis of acceleration records triggered by borehole accelerometers during actual moderate earthquakes. The underground accelerations were measured at three observatory sites around Tokyo Bay—Ukishima Park, Futtu Cape, and Kannonzaki. At the Ukishima Park site, consisting of reclaimed soils, silts, clays,

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

and sands, accelerometers were installed at four levels: on the ground surface, and at 27 m, 67 m, and 127 m below the surface. At the Futtu Cape site, where comparatively uniform sand layers exist, accelerometers were installed at the surface and 70 m and 110 m below the surface. At the Kannonzaki site, consisting of silty stones with a shallow top soil, accelerometers were installed at the surface and 80 m and 120 m below the surface.

The distributions of maximum ground acceleration are displayed for specific earthquakes. The distributions of maximum acceleration are also represented in terms of average underground acceleration. Shown are transfer functions (amplitude) of the ground between two levels computed from the horizontal accelerations at the Ukishima Park and Kannonzaki sites. These results confirm that the computed transfer functions are almost identical for several earthquakes, although the motions have different frequency characteristics. The results also show that the computed transfer functions are in fairly good agreement with the theoretical transfer functions, which are based on multiple reflection theory. The transfer functions computed from the vertical component of the accelerations are shown. They are very different from those of the horizontal components. The transfer functions are also computed for time intervals of 5 sec in order to show the changes in the time domain. The underground motions were computed prescribing the measured surface motion and they are satisfactorily correlated with the measured ones. Computed and measured underground motions are compared in terms of acceleration response spectra.

● **3.5-30** Tomizawa, M., **Least squares estimation of dynamical characteristics of soil-layers and of power spectral density of bedrock excitation** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 11, Nov. 1978, 81–88.

System identification for a bedrock-soil-layer model subjected to excitation has been performed. From the velocity data of the El Centro 1940 and the Taft 1952 earthquakes, damping coefficients and spring constants for the equivalent multi-lumped-mass system of the soil layers and the power spectral density function of white system noise are estimated. Two assumptions are made in this paper: (1) observations such as the subset of earthquake ground velocities are assumed to be a weakly stationary stochastic process, and (2) measurement noise caused by both the measurement error process and data processing is assumed to be negligible.

● **3.5-31** Kobayashi, K. and Kobayashi, H., **Nature of microtremors in wide period range depends on ground characteristics,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 39, Nov. 1978, 305–312.

The relationship between the nature of microtremors in the period range 0.1 to 10 sec and deep soil structure characteristics is discussed. Field measurements of microtremors that occurred for twelve days at Ukishima, Kawasaki, Japan, are evaluated. An analysis of the results indicates that: (1) SH-wave components showed a diurnal variation and that the period range was shorter than 2 sec; (2) in the period range longer than 2 sec, Rayleigh waves predominated and these waves varied according to atmospheric and oceanic wave conditions. A ratio of the vertical-component amplitude to the horizontal-component amplitude for Rayleigh waves was calculated from multilayered subsoil structures and compared with the ratio obtained from field measurements. Good agreement was achieved, confirming that the measurements of longer period microtremors are applicable for evaluating the effects of atmospheric conditions on deep ground characteristics.

● **3.5-32** Taga, N. and Miyazaki, T., **Microseisms in the Nohbi Plain** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 40, Nov. 1978, 313–320.

Microseisms were observed in 1976 along two geological lines near the center of the Nohbi Plain. Long-period seismometers with 10-sec periods were used. A continuation of observations of microseisms was carried out in 1977 along two other geological lines that cross transversely. Seismometers with 1- and 5-sec periods were used. The waveforms of the observed microtremors are digitized by use of an A/D converter and analyzed by the Fourier technique. Spectra are compared with soil layer thickness corresponding to a depth of 1300 m, and waveforms are discussed.

The results indicate that: (1) The vibrational properties in the plain vary from 0.2 to 0.43 Hz in the low-frequency range and from 1.5 to 3.0 Hz in the high-frequency range. These frequencies vary according to the type of geological profile. (2) The spectral properties of the horizontal components can be obtained by an investigation of the amplification spectrum for the body wave. (3) The period corresponding to the minimum group velocity of the dispersion properties for surface waves such as Love and Rayleigh waves agrees well with the predominant period for the microseisms. (4) It is presumed that microseisms are composed of a few types of waves. This is based on the particle orbits that are plotted with a digital narrow band-pass filter in the low-frequency range.

● **3.5-33** Ishida, K., **Study on expected value of maximum velocity on the bed rock in the hypocentral area** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 4, Nov. 1978, 25–32.

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This paper discusses a methodology for predicting the maximum velocity at bed rock, and applies it to the Parkfield earthquake of 1966, the Ohita earthquake of 1975, and the Izu-Ohshima earthquake of 1978. The methodology is based mainly on the propagating fault model formulated by Haskell (1975). The statistical, empirical formula for attenuation of earthquake ground motion proposed by K. Kanai is used to estimate overall effects which cannot be estimated by the simple fault model.

● 3.5-34 Chang, F. K. and Krinitzsky, E. L., **Effects of magnitude, distance, and site conditions on duration of strong earthquake motions,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 5, Nov. 1978, 33-40.

The observed spread in the frequency content of strong-motion accelerograms does not vary greatly with duration, magnitude, and site geological conditions, although there is a predominance of low frequencies (<2 Hz) at alluvial sites. Maximum bracketed durations (≥ 0.05 g) appear to be greater in soil sites than in rock sites by a factor of at least 2 to 1. A decrease in bracketed duration with distance from source is very pronounced for soil sites in the near field. Resonance can greatly increase the duration of shaking, particularly in soft alluvium.

● 3.5-35 Irikura, K. and Kawanaka, T., **Characteristics of microtremors in a ground with steeply varying structure,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 38, Nov. 1978, 297-304.

Reports of earthquake damage have frequently noted that damaged regions are sometimes confined to small zones in which the local geological configurations have steeply lateral variations. These reports indicate that it is necessary that the engineering-seismological study estimate the amplification effects of earthquake motions caused by lateral interference associated with a geological irregularity as well as those effects caused by vertical interference within the flat surface layers.

In this paper, the characteristics of microtremors, observed at an area where the underground structure is estimated to contain horizontally irregular interfaces, are examined. The spatial correlation characteristics of microtremors are significantly affected by the horizontal irregularity of surface layers, and the lateral variations of the amplitudes of microtremors are explainable by the transmission and reflection of surface waves at vertical discontinuities. Observation of microtremors using a horizontal array is an efficient method for detecting zones with lateral irregularity of the local geology. Such observations also aid in predicting the spatial variations of seismic wave responses caused by lateral interference.

● 3.5-36 Seo, K., **Earthquake motions modulated by deep soil structure of Tokyo,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 36, Nov. 1978, 281-288.

The objective of this study is to determine the characteristics of long-period earthquake ground motions in the period range from 1 to 10 sec. In addition to source mechanism characteristics, deep subsoil structures at a site must be considered. By using the results of several studies on seismic prospecting, seismic-wave paths, and observations of long-period earthquake ground motions, sedimentary layers of about 2.3 km thickness in Tokyo were confirmed to have a strong influence on long-period ground motions. Most important, during a shallow and near-field earthquake of large magnitude, a major part of the Tokyo metropolitan area could be subjected to such ground motions. It is recommended that seismic zoning take into account deep subsurface structures as well as shallow structures.

● 3.5-37 Trifunac, M. D. and Anderson, J. G., **Preliminary empirical models for scaling pseudo relative velocity spectra,** *CE 78-04,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, June 1978, 87.

In this report a method is presented for direct scaling of pseudo relative velocity spectra (PSV) in terms of (1) earthquake magnitude and epicentral distance, or (2) modified Mercalli intensity (MMI) at a site. These models depend directly on the geologic site conditions and are presented for horizontal and for vertical ground motions. This scaling is realized by means of "coefficient" functions which are determined by regression analysis of computed PSV spectra from recorded accelerograms. The resulting shapes and amplitudes of PSV spectra depend on all scaling parameters. One of the principal advantages of the proposed method is that the ambiguities associated with the scaling of the fixed-shape spectra by means of peak amplitudes of ground motion are now completely eliminated. The 91 direct regressions of 372 horizontal and 186 vertical spectra, at 91 periods, smoothed over all periods, lead to more complete and reliable sampling of the frequency-dependent characteristics of strong ground motion than the correlations of peak amplitudes alone.

● 3.5-38 Trifunac, M. D. and Anderson, J. G., **Preliminary empirical models for scaling relative velocity spectra,** *CE 78-05,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Aug. 1978, 69.

This report presents two empirical models for the estimation of relative velocity spectrum amplitudes (SV) for scaling in terms of (1) earthquake magnitude and epicentral distance or (2) modified Mercalli intensity at the

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recording station. These models also present the dependence of SV amplitudes on geologic site conditions, the horizontal or vertical direction of motion, and the selected confidence level that the chosen spectrum amplitudes will not be exceeded.

● **3.5-39** Inatomi, T., Uwabe, T. and Nakamura, R., **Earthquake observation of substructure made of hard treated soil and its surrounding soft ground** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 20, Nov. 1978, 153-160.

The deep mixing method (DMM), one of the methods for stabilizing clayey soils with chemical material, has recently been developed. However, some problems remain to be solved for the seismic-resistant design of ground stabilized with DMM. One problem is that interaction between the substructure and the surrounding soft ground during earthquakes has not been well analyzed. Recently, an entire stratum of soft ground beneath an upper structure was stabilized by DMM at the Daikoku wharf in Yokohama port. Earthquakes were recorded at the site. This paper presents an outline of the observation system, the records obtained, and the results of an analysis of the data.

Borehole accelerometers were installed on the untreated ground and on the treated substructure. Ground conditions at the site are summarized. Since January 1978, seven records have been obtained. Schematic distributions of the observed maximum accelerations of each earthquake are given. The amplification ratios of the maximum values at each accelerometer point to the maximum accelerations at base rock and the acceleration records of one earthquake are shown. To investigate the frequency characteristics of waves at the accelerometer points in the upper ground and the substructure, power spectra were computed for the earthquake. Power spectra at every accelerometer point are shown. Spectral ratios between accelerometer points were computed by taking the ratio of the square root value of the power spectrum.

Results can be summarized as follows: (1) The treated substructure behaved as a rigid body. (2) The observed maximum acceleration at the top of the substructure was low in comparison with that at the top of the untreated ground. Ratios of these maximum accelerations were about one-half in the transverse direction and one-third in the longitudinal and vertical directions. (3) The maximum acceleration of the substructure is nearly equivalent to the average value of the maximum acceleration of the untreated soft ground surrounding the substructure. (4) The response acceleration of the substructure is nearly equivalent to that of the untreated parts interspersed between the substructures.

● **3.5-40** Yokota, H., Watanabe, H. and Shioya, K., **Characteristics of 1-10 sec ground motions observed in Tokyo** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 19, Nov. 1978, 145-152.

In recent years, various types of large-scale structures with long natural periods have been constructed. For this reason, it has become important to investigate the characteristics of 1-10 sec components of strong ground motions. In this paper, the relationship between the characteristics of 1-10 sec ground motion components and the deep underground structure of Tokyo is investigated.

Earthquake observations have been carried out at Shibaura, Minato-ku, and Toyosu, Koto-ku. At Shibaura, three-component accelerometers were installed at three points vertically in the soil; and, in order to observe the long-period component, three-component velocity seismometers were set on the ground surface. At Toyosu, two-component accelerometers were installed at four points in the soil. Many earthquakes containing long-period components have been recorded. From the result of spectrum analyses of these records, it was found that the predominant periods in the range of 1-10 sec were 1.2 sec, 2.0 sec, 3.5 sec, 5.0 sec, and 7-9 sec. These predominant periods were compared with those periods from an analytically obtained transfer function. The multireflection theory was used to take into account the deep underground structure of Tokyo. Since all the observed and theoretical predominant periods agree well with each other, except for the 5-sec component, the amplification characteristics of the deep underground structure can be explained fairly well by using a layered-soil model having a depth of 2.5 km. For the velocity records of the 1978 near Izu Ohshima earthquake, the loci of 5-sec components and 7-9 sec components were obtained and also the running spectra of the records were calculated. From the results of the running spectrum analysis, the dispersion curves of the surface wave group velocity were calculated and compared with the theoretically obtained dispersion curves. From an analysis of the results, it is concluded that the 5-sec component observed in Tokyo is a Rayleigh wave and that the 7-9 sec component is a Love wave. Dispersion curves of the observed results agree well with the curves of the theoretical results.

● **3.5-41** Ohta, T., Niwa, M. and Andoh, H., **Seismic motions in the deeper portions of bedrock and in the surface and response of surface layers** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 17, Nov. 1978, 129-136.

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The characteristics of seismic motions on the ground surface are currently analyzed with data obtained from the bedrock to the surface. In the present study, the acceleration observed at the bedrock at a depth of 3.5 km and that observed concurrently at another location near the ground surface are used to analyze the response near the ground surface resulting from the bedrock input motion. The seismic waves analyzed are recorded in the bedrock at Iwatsuki, a suburb of Tokyo, and at six simultaneous observation points in the depth range of 2 m to 100 m at Ohji in Tokyo. Two of the three earthquakes observed at these locations are analyzed in detail. The velocity response spectrum of the earthquake observed in the bedrock approaches a constant in the period range of 0.1 to 5 sec when the damping ratio is equal to 0.05 and decreases gradually in the shorter period.

The propagation characteristics of the wave motion are examined including the identification of the surface wave using the data obtained near the surface. The analytical methods include: (1) comparison of the amplification spectrum and the transfer function using the data obtained at GL-100 m and GL-2 m; (2) identification of the wave by the particle orbit of the component, supposedly the surface wave; (3) calculation of the group velocity and the phase velocity of the surface wave in the ground surface layer and comparison of the velocities with other characteristics; and (4) confirmation of the existence of a dispersion wave by means of a running Fourier spectrum. As a result, Love waves of 1.3 Hz and 3 Hz were confirmed. In addition, by applying bedrock motion as an input to the ground model 3.5 km in depth, the SH-wave response was calculated, and to this were added major components of a Love wave separated in advance. The calculated and observed waves at the ground surface show good agreement.

● 3.5-42 Kokusho, T., Iwatate, T. and Ooaku, S., **Scaled model tests and numerical analyses on nonlinear dynamic response of soft grounds**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 96, Nov. 1978, 761–768.

Shaking table tests have been performed to represent the nonlinear vibration of soft grounds subjected to strong earthquake motions. Special care has been taken to design a soil container that will reproduce idealized horizontal shear wave propagation in the model ground. Nonlinear acceleration responses to various random motions measured in the model ground are compared with numerical results obtained by the equivalent linear analysis widely used in engineering practice. This comparative study reveals the general efficiency of the analytical technique for the engineering prediction of earthquake motion of soft grounds, although the analysis gives a poorer prediction for smaller amplitudes in the random motion.

● 3.5-43 Sugimura, Y., **Relation between velocity response and shear strain in ground during earthquakes** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 95, Nov. 1978, 753–760.

Seismic shear strain induced in ground during earthquakes is computed from observed earthquake ground motion data by using elastic wave propagation theory and equations shown in the paper. Ten earthquakes recorded at Toshima 5 Chome in Tokyo are selected as analytical examples. The soil profile of the site, the parameters of the earthquakes, the map of the station, and the epicenters are presented. Fifty-seven strong-motion records in California are also analyzed in the same way, and the results of the Toshima site and the sites in California are compared statistically. Time histories of the seismic shear strains at every one-tenth depth of the top layer and the second layer at the Toshima site are shown for the EW component of the Izu Hantoh-oki earthquake (May 9, 1974). The distribution of shear strain in the ground at the time that the maximum value appears for the NS and the EW components is given. The relation between the maximum shear strain and the epicentral distance suggests that the greater the seismic magnitude, the larger the maximum shear strain. The relationship is compared between the maximum shear strain and the maximum velocity at the ground surface for the Toshima site and for California. The first-order linear function, calculated using the least-square approximation method, is given by equations. The coefficients of these equations are slightly different, i.e., it appears that the softer the soil, the greater the coefficients. A method for determining the relationship between earthquake intensity and ground behavior is suggested. For example, if soil behavior can be classified from dynamic laboratory soil tests into three different ranges, such as elastic, medium, and plastic states, around the boundaries of the maximum shear strains $3 \times 10^{-2}\%$ and $1 \times 10^{-1}\%$, the values 10 and 30 kines, respectively, on average will correspond to the boundaries of the ground shaking.

● 3.5-44 Imai, T., Fumoto, H. and Tonouchi, K., **The relation of S-wave velocity and soil characteristics alluvial sand** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 94, Nov. 1978, 745–752.

Past studies have revealed that S-wave velocity is related to the constants representing ground strength and deformation characteristics, i.e., N values, lateral ground coefficients, and unconfined compression strengths. However, these studies have not considered the major factors that determine the S-wave velocity of soil. Depending upon the difference in size and configuration of the external forces applied to soil, the response values, namely, the strength and deformation characteristics, can vary. The S-wave velocity also can be regarded as one of the response

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values which reflects the condition and constitution of soil. In this paper, a detailed review is conducted of the influence of geotechnical constants on the determination of S-wave velocity. Alluvial sandy soil, which is commonly found close to the ground surface, is examined.

● **3.5-45** Iida, K. *et al.*, **Seismic characteristics of the ground and earthquake risk in Nagoya area** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 178, Nov. 1978, 1415–1422.

Shear wave velocity, soil density, and N-values at 35 boring points in the Nagoya area were measured by means of P- and S-wave velocity data up to about 100 m in depth. By using these underground data as well as soil characteristics, empirical equations for estimating shear wave velocity and density were derived. Shear wave velocity and density at depth for about 400 mesh points were calculated. By using derived equations and boring data, seismic response spectra and ground amplification characteristics were obtained by means of Herrera's and Rosenblueth's shear wave multireflection method. The results are the following: (1) In the western part of the Nagoya area, the maximum amplification factor is large, especially in the northwest and in the coastal area where the factor is larger than 6; (2) The relationship between the amplification factor and damage ratios in the 1891 Nobi and 1944 Tonankai earthquakes shows that earthquake damage is large in an area where the amplification factor is larger than 6; and (3) The northwest and the coastal area as well as the area in Nagoya with an amplification factor larger than 6 are considered to be high seismic risk areas.

● **3.5-46** Muzzi, F. and Pugliese, A., **Analysis of the dynamic response of a soil deposit in locality "Ca-Dant" (Corino-Forgaria)**, *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations*, **Vol. II**, 541–566. (For a full bibliographic citation, see Abstract No. 1.2-7.)

In this paper, the dynamic behavior of a soil is studied. An alluvial deposit underlain by a sloping bedrock was instrumented with two strong-motion recorders located 650 m apart. One instrument was installed on the outcropping bedrock; the other, at the surface of the alluvial deposit where the thickness was about 15-20 m. The results were based on measured ground accelerations from aftershocks having magnitudes varying from 4.2 to 6.1. Since real outcropping motions also were available, it was possible to obtain an instrumental indication of the correlation of magnitudes and hypocentral distances with the dynamic response of the soil deposit. The data showed a maximum peak surface acceleration at certain distances. A finite element analysis was performed on approximately defined mechanical and geometrical properties of the soil profile. The computer program QUAD 4 was used. The validity of such investigations was confirmed because the theoretical results agreed with the recorded values. It was shown how a loose deposit underlain by a sloping base rock could produce amplifications of the ground surface motions varying from 1.5 to 3.8.

● **3.5-47** Berardi, R., Capozza, F. and Zonetti, L., **Analysis of rock motion accelerograms recorded at surface and underground during the 1976 Friuli seismic period**, *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations*, **Vol. II**, 527–540. (For a full bibliographic citation, see Abstract No. 1.2-7.)

During the seismic sequence that started in Friuli on May 6, 1976, a few shocks were recorded simultaneously by strong-motion accelerographs located on outcrops of bedrock and underground at several depths. These instruments were installed by the Italian Electricity Board (ENEL) at the site of the Somplago hydroelectric plant which is quite close to the epicenters of the recorded shocks. More than eighty records were taken with these instruments, some of which were related to the same shock. Analysis of these accelerograms and a comparison of the results provided information which contributes towards a better understanding of rock motion during an earthquake, both at the surface and underground.

● **3.5-48** Muzzi, F. and Vallini, S., **The Friuli 1976 earthquake considered as a "near source earthquake." Presentation and discussion of the surface recordings**, *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations*, **Vol. II**, 460–526. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Most of the instruments that were triggered during the Friuli seismic sequence were located within 20 km from the epicenter of each event. All the obtained records have been analyzed, and for each earthquake a map has been drawn showing the distance of each accelerograph station from the epicenter, the magnitude, the focal depth, and the maximum acceleration recorded by each station for the three ground motion components. Since many aftershocks with magnitudes varying from 4-6 have been recorded, the data are suitable to investigate the variation of parameters with magnitude and distance from a given site. In particular, knowledge of the soil profile and the elastic soil properties beneath each accelerograph station has made it possible to correlate the maximum surface acceleration with distance, magnitude, and local soil conditions. It appears that, for all sites characterized by a soft deposit underlain by bedrock, maximum surface acceleration does not decrease monotonically with distance from the epicenter but reaches a maximum for a certain distance from the epicenter. This confirms the influence that local soil conditions have on surface motion, and the Friuli earthquake showed this influence particularly in the range of the distances of the accelerograph stations from the epicenters and in the range of the magnitudes of the aftershocks.

● 3.5-49 Taga, N. and Miyazaki, T., **Microseisms in the Nohbi plain** (in Japanese), *Transactions of the Architectural Institute of Japan, 269,* July 1978, 103-114.

Microseisms were observed along two geological lines near the center of the Nohbi plain by use of a long-period (10-sec) seismometer. The wave forms of the observed seisms were digitized by the A/D converter and analyzed by the Fourier transform technique. The vibrational properties of the plain are in the range of 0.2 to 0.3 Hz in the low frequency, 0.5 to 0.6 Hz in the middle frequency, and 1.5 to 3.0 Hz in the high frequency. The numerical results and spectral forms are discussed and compared with the geological profile of the plain, the sea wave properties of Ise Bay, Bouguer's anomaly, and the wave propagation properties.

● 3.5-50 Taga, N. and Miyazaki, T., **Microseisms in the Nohbi Plain (part 2)** (in Japanese), *Transactions of the Architectural Institute of Japan, 273,* Nov. 1978, 33-42.

A continuation of previous observations of microseisms was carried out along two geological lines that cross transversely in the Nohbi plain. A seismometer with 1-sec and 5-sec periods was used. The digitized data are analyzed by the fast Fourier transform method. Spectral forms of the analytical results are compared with observations for soil layers 1300 m in depth and discussed from a wave viewpoint. The horizontal component properties of the microseisms nearly agree with the wave transfer properties of SH-waves and the wave dispersion properties of Love waves. The vertical component properties of the microseisms may be similar to Rayleigh wave properties.

● 3.5-51 Ozaki, M., Kitagawa, Y. and Hattori, S., **Study on regional characteristics of earthquake motions in Japan (part 1)—earthquake danger based on seismic activity and its practical application** (in Japanese), *Transactions of the Architectural Institute of Japan, 266,* Apr. 1978, 31-40.

One of the most important problems in earthquake engineering is to predict the intensity of future earthquakes statistically from past available earthquake recording data. The selection of the past earthquake recording data and the method of statistical analysis are important, because the available earthquake recording data are insufficient. Much research in this field has been carried out in Japan, although not using the theory of extremes developed by E. J. Gumbel.

This paper considers the expected values of intensity for future earthquakes, primarily on base rock. The following data and methods are used: (1) earthquake data in the vicinity of Japan for the period of 1644 to 1972; (2) Kanai's formulation which gives a maximum intensity at the base rock and on the surface of the ground; and (3) Gumbel's second asymptotic distribution in the statistics of extremes. Especially for the data from earthquakes which occurred before 1926, the treatment of the velocity characteristics at the base rock is as follows: (1) major earthquakes having a velocity of 2.5 cm/sec or more at the base rock are estimated from the destructive earthquakes listed in the *Science Calendar*; and (2) it is assumed for small or medium earthquakes with velocities less than 2.5 cm/sec at the base rock that the frequency of earthquake occurrence is the same as that after 1926.

The expected maximum velocity at the base rock with standard deviation vs. return period is predicted at the center of Tokyo (35.7°N, 139.8°E). The expected maximum acceleration, velocity, and displacement at the ground surface and the calculated maximum velocity values at the base rock for each year are listed in tabular form. Regional distributions of the expected maximum velocity at the base rock are estimated for 50-, 100-, and 200-year return periods for the vicinity of Japan. The areas where the earthquake danger is considered to be high are generally as follows: (1) the coastal area on the Pacific Ocean side from the Hokkaido to Tohoku and Kwanto districts; (2) the area from the western part of the Chubu district to all parts of the Kinki district; and (3) the area from the western part of the Shikoku to the eastern part of the Kyushu district. For practical seismic design purposes, a regional seismic zoning map is proposed which reflects past seismicity. The map divides Japan into three categories: a high seismicity region, a middle seismicity region, and a low seismicity region.

● 3.5-52 Shibata, T., Sato, T. and Soelarno, D. S., **Dynamic behaviour of soils and sub-surface ground,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/40, 1977, 393-396.

This paper considers the behavior of soils under cyclic loading. A constitutive relation between shear stress and strain and effective confining pressure is proposed and checked by means of dynamic triaxial tests. A soil model is proposed to represent the equivalent shear modulus, strain, and confining-pressure relations for small strain levels. The behavior of a subsurface ground during an earthquake is analyzed by using the proposed soil model and the wave propagation theory that has been obtained as an extension of the multiple wave reflection theory. Data recorded during strong earthquakes are used as input to investigate the influence of the nonlinear behavior of the soils on the stress and strain developed in the ground.

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● 3.5-53 Okada, S. and Kagami, H., **A point-by-point evaluation of amplification characteristics in Japan on 1~10 sec seismic motions in relation to deep soil deposits** (in Japanese), *Transactions of the Architectural Institute of Japan, 267,* May 1978, 29-38.

The amplification characteristics of earthquake ground motions in the period range from 1 to 10 sec in large areas of Japan are used to investigate the dynamic earthquake resistance of highrise and large-scale structures. The data used in this analysis were obtained from strong-motion displacement seismographs with a natural period of 6 sec located at approximately 100 local observatories operated by the Japan Meteorological Agency. All the shallow and moderate-to-large earthquakes which occurred in and around Japan for a recent 15-year period were selected for analysis. The total number of earthquakes was 138. Plots of maximum amplitude as a function of epicentral distance show large scatters which are attributed to the site conditions. Using a least squares method, an attenuation curve was approximated to the relation between maximum amplitude and epicentral distance for each earthquake. At each site, the deviation from this curve was regarded as an index to express ground characteristics. Deviations for all earthquakes were assessed and a histogram was made. The mean value of the histogram was defined as the most probable amplification of seismic ground motion at each station. The mean values obtained were plotted on a map of Japan, thereby giving a general view of ground characteristics in Japan. Very high values are seen at such large cities as Tokyo, Osaka, and Niigata. A detailed survey of the ground characteristics was carried out in the Kanto plain. The results revealed that amplification increases with increasing depths to the basement at the site and that the depths relating to ground motions in the period of 1 to 10 sec are from one hundred to several thousand meters.

● 3.5-54 Midorikawa, S. and Kobayashi, H., **Spectral characteristics of incident wave from seismic bedrock due to earthquake** (in Japanese), *Transactions of the Architectural Institute of Japan, 273,* Nov. 1978, 43-54.

It is well known that the spectra of earthquake ground motions observed on the surface can be regarded as the product of the spectrum of the incident wave on bedrock and the amplification factor of the ground. Many studies on the amplification characteristics of the ground have been made. Several empirical formulas of the maximum amplitude of seismic bedrock motions have been proposed, but there have been only a few quantitative studies on the spectral characteristics of seismic bedrock motions and the definition of the bedrock was not unified in these studies. In this paper, the authors obtain the velocity response spectra of incident waves at bedrock by using observed surface ground motions. The characteristics are examined.

● 3.5-55 Ishida, K., Watabe, M. and Osaki, Y., **Analysis on earthquake ground motions including vertical components (Part 2: results of numerical analysis on effects of soil condition and source mechanism of a fault, especially slip vector and dip angle)** (in Japanese), *Transactions of the Architectural Institute of Japan, 274,* Dec. 1978, 9-15.

This paper examines the numerical results of an analysis of the effects of soil condition and source mechanism on the vertical component of ground motion. The results are as follows: (1) Because of the amplitude characteristics of layered soil, the predominant periods of observed vertical seismograms are shorter than for horizontal seismograms; (2) as the layered crust becomes soft, the amplitude rate of the soil increases; (3) the angles of incidence of *P*-waves and *SV*-waves at the layered crust have an important effect on the amplitude characteristics of the layered crust, with *SV*-waves being more significant; (4) as the soil layer becomes soft, there is an increasing ratio of maximum vertical to horizontal amplitudes; (5) the slip vector of the fault plane has a significant effect on the vertical component of seismograms. The dip-slip type fault has a more significant effect than a strike-slip fault; (6) the dip angle of the fault strike has a significant effect on the quality of the vertical component of seismograms. In the case of the strike-slip fault, the vertical ground motions increase as the dip angle decreases. For a dip-slip fault, determining the quality of the vertical component is more complex because of the location of the seismograph station, the fault strike, and the dip angle.

3.5-56 Kobayashi, H., **A method for seismic microzoning maps on the basis of subsoil conditions**, *Bollettino di Geofisica,* **XX**, *78,* June 1978, 145-164.

The distribution of seismic damage to buildings is related to the nature of the ground and to the properties of the buildings. As such, the distribution varies with the building type. The distribution of seismic intensities is considered in conjunction with the natural period of buildings. Amplification and modification of incident waves under differing ground conditions are treated in this paper by means of the theory of shear wave propagation in a multilayered soil system undergoing multiple reflection. The response of each layer can be calculated in the time domain, and the incident waves at bedrock can be reproduced from an observed earthquake at the ground surface. The distribution of seismic intensities for buildings in Kawasaki City is inferred in terms of the natural periods of the buildings. Seismic ground motions were computed from borehole data of the dynamic properties of the soil. The area is situated on soft alluvium, and the ratio of intensity to the incident wave acceleration is more than ten times at several sites. These phenomena are confirmed by studying the damage to houses caused by the 1923 Kanto earthquake. An improved method for the estimation of incident waves on seismic bedrock is given.

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

● 3.5-57 Kiremidjian, A. S. and Shah, H. C., **Probabilistic site-dependent response spectra**, *Report 29*, John A. Blume Earthquake Engineering Center, Stanford, California, Apr. 1978, 86.

The effects are investigated of local soil conditions on peak ground acceleration, frequency content, and amplification factors. The objectives of this analysis are to (1) obtain peak ground motion modification parameters for correcting the probability distributions of the peak ground acceleration values for the site of interest; (2) develop site-dependent response spectral shapes (or dynamic amplification factors) and probability distributions of the latter for three basic soil types; and (3) develop probability distributions of response spectra at a given location for the three different soil types and to obtain from these distributions design response spectra for a specified risk level.

3.6 Seismic Site Surveys

● 3.6-1 Bertero, V. V., Mahin, S. A. and Herrera, R. A., **Aseismic design implications of near-fault San Fernando earthquake records**, *Earthquake Engineering and Structural Dynamics*, **6**, *1*, Jan.-Feb. 1978, 31–42.

Near-fault records of the 1971 San Fernando earthquake contain severe, long-duration acceleration pulses which result in unusually large ground velocity increments. A review of these records, along with the results of available theoretical studies of near-fault ground motions, indicates that such acceleration pulses may be characteristic of near-fault sites in general.

The results of an analytical study of a building severely damaged during the San Fernando earthquake indicate that such severe, long-duration acceleration pulses caused most of the observed structural damage. The implications of such pulses for current aseismic design methods, particularly those used to establish design earthquakes, are examined for buildings located near potential earthquake faults. Analytical studies of the nonlinear dynamic response of single and multidegree-of-freedom systems to several near-fault records, as well as to a more standard accelerogram, indicate that at near-fault sites: (1) very large displacement ductilities may result for current levels of code design forces; (2) smoothed elastic design response spectra should reflect the larger ground velocities that may occur; and (3) peak inelastic response cannot reliably be inferred from elastic response predictions.

● 3.6-2 Donovan, N. C. and Bornstein, A. E., **Uncertainties in seismic risk procedures**, *Journal of the Geotechnical Engineering Division, ASCE*, **104**, *GT7*, Proc. Paper 13896, July 1978, 869–887.

Probabilistic and statistical methods are being used more widely in seismic risk analyses. These procedures allow maximum use of geologic and seismological input into the evaluation of probable risk levels expected at a site. The seismic parameters must be based upon as complete and accurate a data set as possible, and the relationships derived from the data must be consistent and representative of that data base. Several case histories are presented. Each demonstrates difficulties inherent in most data sets and methods to overcome them.

● 3.6-3 Hays, W. W., **Ground-response maps for Tonopah, Nevada**, *Bulletin of the Seismological Society of America*, **68**, *2*, Apr. 1978, 451–469.

Ground-response maps for Tonopah, Nevada, were prepared using ground-motion data from a Nevada Test Site explosion recorded on a 12-station seismic array in Tonopah. These data were used to define 10 frequency-dependent ground-response maps for the period range 0.05 to 2.5 sec. These data were combined with the probabilistic calculation of earthquake ground accelerations on rock sites in the Tonopah area, made in a 1976 study by S. T. Algermissen and D. M. Perkins, in order to give estimates of the ground shaking expected throughout the city in a 50-yr period at the 90% probability level. Although these relative ground-response estimates are based on low-strain data, they provide a preliminary basis for delineating geographic areas with different susceptibilities to earthquake ground shaking until the time that high-strain earthquake ground-motion measurements become available in Tonopah.

● 3.6-4 Katz, L. J. and Bellon, R. S., **Microtremor site analysis study at Beatty, Nevada**, *Bulletin of the Seismological Society of America*, **68**, *3*, June 1978, 757–765.

Current microzonation mapping procedures often call for the generation of complicated mathematical ground-motion models. These models require that expensive geophysical and geological surveys be performed to gather input information. A more desirable method of estimating ground motions would be to measure these effects directly. Microtremor analysis procedures provide such a direct method. Microtremor data were collected at several sites at Beatty, Nevada, and compared to nuclear event and mathematical model ground-motion spectra. The frequency at which peak amplitudes occurred on all spectra agreed. These frequencies appear at the resonance frequency of the surface layer when stimulated by compressional waves. Results of this experiment add validity to the use of microtremors in microzonation studies.

● 3.6-5 Ferritto, J. M., **A probabilistic procedure for estimating seismic loading based on historic and geologic**

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data, *R-867,* Civil Engineering Lab., U.S. Naval Construction Battalion Center, Port Hueneme, California, Aug. 1978, 240. (NTIS Accession No. DN 887 007)

This report describes a procedure for estimating site ground motion based on the historic data base of earthquakes adjusted to incorporate fault slip data. Procedures are given for determining site acceleration magnitude and duration for various confidence levels. Seismic risk analysis techniques are discussed, and background material required for an understanding of the procedure is presented.

● **3.6-6** Goldsmith, M., ed., **Literature survey of selected topics pertinent to underground siting of nuclear power plants,** *5030-83,* Jet Propulsion Lab., Pasadena, California, May 1977, 133.

● **3.6-7** Yegian, M. K. and Whitman, R. V., **Risk analysis for ground failure by liquefaction,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT7,* Proc. Paper 13900, July 1978, 921–938.

An empirical risk analysis method has been developed for studying the likelihood of earthquake-induced ground failure by liquefaction. The method is based on interpretation of case histories in terms of earthquake magnitude and hypocentral distance. Using this method, the probability of liquefaction at a site as a function of earthquake magnitude and hypocentral distance is first evaluated, then integrated over all magnitudes and distances of interest to obtain the total annual probability of liquefaction at the site. An example study evaluates the overall risk of liquefaction at a site.

● **3.6-8** Murphy, V. J., **Geophysical engineering investigative techniques for site characterization,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 153–178.

Geophysical surveys of a regional nature and of a site-specific nature, the latter usually including in-situ measurements of seismic wave velocity values, are the most generally accepted applications of geophysical engineering techniques for microzonation/site characterization. The need to know where earthquakes are likely to occur and the effects of those earthquakes on different geologic materials and/or foundation conditions has increased both the use and acceptance of geophysical surveys. Delineation of tectonic elements is desirable, and assessment of the values of moduli at various depths below ground surface is a design requirement.

A myriad of geophysical techniques is readily available from a number of consultants and contractors. There appears to be a universal acceptance of gravity and magnetic surveys for regional studies, and seismic refraction and cross-hole velocity measurements to obtain the in-situ parameters; occasionally, seismic reflection surveys are useful for delineating specific structures (such as offshore faulting) and tracing such structures. Of all the geophysical techniques in any way related to specific site parameters, the in-situ measurement of shear wave velocity values is the most widely used. The method of measurement, that is, the type of energy source and the specific array of boreholes (either closely spaced or spread at relatively great distances), varies with the organization conducting the measurement.

● **3.6-9** Keefer, D. K. *et al.,* **Preliminary assessment of seismically induced landslide susceptibility,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 279–290.

Earthquake-induced landslides have caused much damage to property and the loss of many lives. Studies are currently being conducted to determine the types of landslides most common during earthquakes and to establish criteria for mapping the susceptibility of slopes to earthquake-induced landsliding. This preliminary summary of findings describes the types and number of landslides that occurred during 15 earthquakes. Preliminary criteria are also presented for mapping the susceptibility of slopes to some types of landslides, and these criteria are used to prepare a susceptibility map of an area near San Francisco, California.

● **3.6-10** Youd, T. L. *et al.,* **Liquefaction potential map of San Fernando Valley, California,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 267–278.

Ground failure caused by liquefaction is a primary hazard associated with earthquakes. A first step in avoiding or mitigating this hazard is to recognize where liquefaction is likely to occur. A liquefaction potential map has been compiled for the San Fernando Valley, California, showing areas where conditions may be favorable for the development of liquefaction. The map incorporates assessments of age and type of sedimentary deposits, ground water depth, and expected seismicity into the delineated zones. The map is useful to planners, building officials, engineers, and others responsible for minimizing seismic risk because it points out areas where potential hazards exist and where further investigation, regulation, zoning, or other measures might be required. The map is not sufficient for evaluation

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of the liquefaction potential at an individual site. Site-specific geotechnical investigations are required to make such an assessment.

● **3.6-11** **Verification of subsurface conditions at selected "rock" accelerograph stations in California,** *Vol. 1,* Shannon & Wilson, Inc. and Agbabian Assoc., Seattle, Washington and El Segundo, California, May 1978, 200.

Studies were conducted at 19 accelerograph station sites in southern California which have been categorized by other researchers as "rock" sites. Each site was visited, and available geotechnical data was compiled to verify the subsurface conditions. At five locations, where the subsurface conditions could not be verified by these means, a single boring was advanced to investigate the subsurface soils. The results are divided into two sections, covering the Central Los Angeles district and the Northern Mountains district. Presented in each section are specific data on each station, including descriptions of station housing, instrumentation, and subsurface conditions. Regional and local geology and structure and seismicity of the study areas are also discussed. Information on the earthquakes recorded at each of the stations, including ground motion time history plots, response spectra curves, and soil boring logs made by others in the site areas are presented in appendexes.

● **3.6-12** Packer, D. R. *et al.*, **Auburn Dam—a case history of earthquake evaluation for a critical facility,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 457–470.

The proposed Auburn Dam is to be located on the north fork of the American River near Auburn, California, on the western margin of the Sierran foothills, an area of few damaging earthquakes during historical time. On Aug. 1, 1975, a magnitude 5.7 earthquake and associated surface faulting occurred in the Sierran foothills near Oroville, 70 km northwest of Auburn Dam. Subsequent investigations revealed evidence of previous Quaternary displacements along this fault. Because of the possibility of surface faulting and earthquakes along other faults in the western Sierran foothills, the U.S. Bureau of Reclamation sponsored an independent and objective reexamination of fault activity in the region to evaluate (1) maximum credible earthquakes of significance to Auburn Dam, (2) earthquake ground motions to which the proposed Auburn Dam may be subjected, (3) the potential for reservoir-induced seismicity resulting from impoundment of the proposed reservoir, and (4) the potential for surface faulting in the foundation of the proposed Auburn Dam.

As a result of these studies, significant contributions have been made to several aspects of earthquake evaluation studies, including detection and evaluation of low-level fault activity along zones of older faulting, evaluation of the potential for reservoir-induced seismicity, the use of multiple parameters in evaluating maximum credible earthquakes, and the use of probabilities and probabilistic evaluations in hazard assessments. In addition, the results indicate the need to consider degree of fault activity in evaluating earthquake hazards to allow judgments to be made regarding acceptable risk.

● **3.6-13** Mardiross, E., **A method for assessment of seismic design motions,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 739–751.

The paper highlights an approach for modifying recorded accelerograms to account for local site conditions. Considerable progress has been made in recent years in setting up a number of strong-motion instruments all over the world; however, until enough data become available, designers should use the described approach to establish design criteria for structures and for microzoning purposes.

● **3.6-14** Justo, J. L., de No, R. L. and Arguelles, A., **A probabilistic estimate of ground motion,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-23, 1978, 167–174.

This research attempts to estimate the most damaging ground motion that will occur at a given site for an accepted probabilistic risk. A record has been defined using several parameters. Statistical multiple regressions have been derived to estimate these parameters from seismic risk data with a standard error as small as possible. A master file, that soon will contain 2000 earthquakes, has been created. The file can be accessed by the use of different computer programs. The final output will be the available record that best suits the conditions of a particular problem.

● **3.6-15** Ishihara, K. and Ogawa, K., **Liquefaction susceptibility map of downtown Tokyo,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 897–910.

To provide a basis for estimating the liquefaction potential of ground during future earthquakes, more than 1,000 boring records obtained in the downtown area of Tokyo were examined and classified into three groups: a possibility of liquefaction, a slight possibility, or no possibility. The classification was based on soil type, stratification, and the standard penetration test N-value. The results showed that liquefaction-induced ground failure could occur at about one-third of the sites investigated.

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● 3.6-16 Marcuson, III, W. F., Ballard, Jr., R. F. and Cooper, S. S., **Comparison of penetration resistance values to in situ shear wave velocities,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 1013–1023.

Standard penetration tests, Dutch cone penetration tests, and rotary cone penetration tests were conducted in adjacent borings in hydraulic fill material at Fort Peck Dam. The dam, located on the Missouri River in Montana, is the Corps of Engineers' largest hydraulic fill earth dam. The dam was constructed during the late 1930s and is approximately 250 ft high (76 m) at its maximum section and 20,000 ft long (6100 m). A geophysical investigation including crosshole, downhole, surface vibratory, and refraction seismic techniques was conducted to determine the in-situ shear wave velocity profile with depth at the penetration test locations. Relationships between the various penetration resistances were developed and correlations between the penetration resistance and the in-situ shear wave velocities are presented. It is concluded that comparisons such as these can assist the engineer in estimating indirectly the shear modulus of in-situ material. This, of course, is an extension of the present study, which is limited to Fort Peck Dam. Future investigations will include the gathering and analysis of data at other test sites.

● 3.6-17 Grant, W. P., Arango, I. and Clayton, D. N., **Geotechnical data at selected strong motion accelerograph station sites,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 983–999.

From 1975 to 1978, the subsurface conditions at more than 70 accelerograph stations in the United States were investigated. The results are contained in a series of reports to the U.S. Regulatory Commission. The format of these reports is summarized in this paper. Since many of the accelerograph stations are located in southern California, the subsurface conditions at selected sites in the Los Angeles basin are discussed. For study purposes, all sites were organized into groups depending upon the depth to bedrock or "rock-like" material: (1) rock at or within 30 ft of the ground surface, (2) rock within 50 to 200 ft of the surface, and (3) rock at a depth greater than 300 ft. The significance of this grouping scheme is discussed, and use of this system is illustrated in plots of peak ground motion for the two extreme data groups. The basic trends of the data are briefly discussed.

3.6-18 Byrne, P. M., **An evaluation of the liquefaction potential of the Fraser Delta,** *Canadian Geotechnical Journal,* **15,** *1,* Feb. 1978, 32–46.

Empirical and analytical methods for predicting the occurrence of liquefaction of foundation soils during an earthquake are examined and applied to the Fraser Delta area of British Columbia. The area is diked and at present has a population of about 150,000 people who reside mainly in low-rise buildings. Liquefaction of the foundation soils would cause severe damage to buildings, services, highway and railway links, and the dikes. Application of empirical methods based on blow count values indicates that liquefaction of the foundation soils could occur. Application of analytical methods indicates that liquefaction could occur in the event of an earthquake having a maximum ground surface acceleration of 0.12 g (the 100 year value). The effects of various remedial measures are examined, and it is shown that densification, drainage, and fill loading reduce the tendency for liquefaction to occur. The presence of a low permeability layer close to the surface may cause liquefaction to occur by impeding the drainage. Construction that involves placing large sand fills with adequate drainage through the surficial low permeability layer to support low-rise buildings seems to be the least hazardous for this region.

● 3.6-19 Yucemen, M. S. and Gulkan, P., **Seismic risk analysis for nuclear power plants** (Nukleer guc santrallari icin deprem riski analizi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **5,** *17,* Apr. 1977, 21–39.

Recent developments in seismic risk evaluation are reviewed to assess the seismic threat at a particular site under consideration for a nuclear power plant. Numerical results obtained from a refined analysis are presented for the site in question.

● 3.6-20 Bennett, J. H., **Foothills fault system and the Auburn Dam,** *California Geology,* **31,** *8,* Aug. 1978, 175–176.

The Oroville earthquake of Aug. 1, 1975, prompted a re-evaluation of seismic hazards in the western Sierra Nevada, and specifically in the Foothills fault system, site of the proposed Auburn Dam. To reassess these concerns, the U.S. Bureau of Reclamation (USBR) retained an engineering consulting firm and appointed a review board of leading specialists. This paper briefly describes the proposed Auburn Dam, and reviews the regional and foundation geology of the dam site. Regional seismicity also is evaluated. At the present time, the USBR and the review board are assimilating the results of these studies and the results of all other investigations conducted in the Auburn Dam area. Further work at the site will be minimal until there is a final resolution of the dam's future.

● 3.6-21 Bedrossian, T. L., **Geology and slope stability in the Geysers Geothermal Resources Area,** *California Geology,* **31,** *7,* July 1978, 151–161.

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● 3.6-22 Durgunoglu, H. T. *et al.*, **A comparison of insitu and laboratory measured dynamic soil properties,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-07, 1978, 39–46.

To obtain reliable data on the dynamic properties of subsurface formations at the Akkuyu nuclear power plant site in Turkey, various in-situ and laboratory investigation procedures have been employed. In-situ measurements in the form of surface refraction, deep-well shooting, and the crosshole technique provided data for the shear and compressional wave velocities. A comparison of compressional wave velocities obtained through different techniques indicates very good agreement.

The compressional wave velocities were also obtained in the laboratory. Sonic velocities of intact core samples were used. The ratio of in-situ and laboratory-measured wave velocities is provided. A static deformation modulus corresponding to large strains is measured by in-situ dilatometer and uniaxial laboratory tests. The ratios of in-situ and laboratory-measured static and dynamic moduli are determined.

● 3.6-23 Tezcan, S. S. and Durgunoglu, H. T., **Subsoil investigation and earthquake design parameters for a nuclear power plant,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-08, 1978, 47–54.

Basic results of the subsoil investigation program for the Akkuyu nuclear power plant in Turkey are presented. The practicality of combining suitably a variety of in-situ and laboratory testing procedures is emphasized. Based on data on the local and regional geology, the tectonics and seismology, and utilizing dynamic soil properties, earthquake design spectra and ground motion time history parameters for the plant are recommended.

● 3.6-24 Stottlemyre, J. A. and Wight, L. H., **A review of potential technology for the seismic characterization of nuclear energy centers,** *BNWL-2396/UC-80,* Pacific Northwest Labs., Battelle, Richland, Washington, July 1977, 91.

This study is part of the ERDA-funded Hanford Nuclear Energy Center Program and is one of a series of technical investigations in support of that program. The study (1) reviews, analyzes, and summarizes the existing seismic evaluation techniques and criteria for the siting and design of individual nuclear facilities, (2) speculates upon possible changes in the criteria in the immediate future, (3) conveys the concept that new seismic criteria may have to evolve to accommodate the magnitude of capital, generating capacity, and nuclide inventory associated with the centralized Nuclear Energy Center (NEC) concept, and (4) identifies techniques and tools that may be available to guide in the drafting of and the compliance with any new seismic criteria.

Risk is often defined as the mathematical product of the occurrence probability of a specific event and the associated consequence. The consequences may be categorized as (1) primary, i.e., the impact of a radioactive release to the biosphere and (2) secondary, i.e., the loss of electrical generating capacity. Assuming that all the facilities within an NEC respond as a unit to an initiating (seismic) event, it would appear that the centralization concept would be a disadvantage. The consequences of an event in excess of the safe shutdown earthquake (SSE) or the design basis earthquake (DBE) would be greater than for the dispersed siting concept. However, if all the funds expended on the siting and seismic design for the dispersed concept were channeled into a single enhanced evaluation of the centralized site, then possibly the error band associated with the SSE and DBE events might be reduced. Furthermore, improved facility design might be implemented because of the more dramatic consequences associated with centralization. The fundamental point is that the NEC concept may motivate technological advancements in the seismically related design and siting of nuclear facilities and may prompt the evaluation of new criteria specifically designed to reduce the risk associated with the centralization concept.

● 3.6-25 Tezcan, S. S. and Durgunoglu, H. T., **Geotechnical and seismic study of the Canakkale-Cardak (Karadere) coal-fired power plant,** *Internal Report 78-22E,* Earthquake Engineering Research Inst., Bogazici Univ., Istanbul, May 1978, 91.

A coal-fired power plant with a generating capacity of 4x200 Mw is to be built by the Turkish Electric Authority near the town of Cardak-Karadere in the province of Canakkale. The power plant is located on the southern coast of the Marmara Sea, along the Canakkale-Bursa highway about 50 km northeast of the city of Canakkale. Soil laboratory tests were conducted on the soil samples taken from the boreholes drilled at the site of the power plant. Microtremors at three different locations and in three components were recorded to determine the predominant periods of vibration of the soil. In this report, the results of the geotechnical and geodynamic studies are presented based on the borehole data, laboratory testing, field observations, seismic refraction, and resistivity survey. The report includes information about the characteristics of subsoil layers, the allowable bearing pressures for various soil conditions, differential settlement considerations, and recommendations for the selection and design of foundations. Also included are a seismic risk analysis, a soil amplification survey, and the parameters of a design earthquake. The seismicity and the seismogenetic information of the region are investigated. By considering the local subsoil

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conditions, the maximum probable magnitude of an earthquake likely to occur within the economic life-span of the power plant is estimated. The maximum probable ground acceleration and the properties of an elastic design acceleration response spectra are also included.

● 3.6-26 Tezcan, S. S. and Durgunoglu, H. T., **Subsoil investigation and earthquake design parameters for a nuclear power plant,** *Internal Report 78-19E,* Earthquake Engineering Research Inst., Bogazici Univ., Istanbul, Apr. 1978, 8.

Results are presented of the subsoil investigation program for the Akkuyu nuclear power plant in Turkey. The practicality of suitably combining a variety of in situ and laboratory testing procedures is emphasized. Earthquake design spectra and ground motion time history parameters are recommended based on dynamic soil property data and on data concerning the local and regional geology, tectonics, and seismology.

3.6-27 Legget, R. F. and LaSalle, P., **Soil studies at Shipshaw, Quebec: 1941 and 1969,** *Canadian Geotechnical Journal,* **15,** *4,* Nov. 1978, 556-564.

The Saint Jean Vianney landslide of May 4, 1971, has prompted interest in soil studies conducted in 1941 as part of the site investigation program for the adjacent wartime Shipshaw power project. These studies included early investigations of Leda clay, the sensitivity of which was recognized but not fully understood. Buried organic matter was encountered at one dam site. The possibility that landslide action accounted for the unusual position of this material was discounted in 1941. Recent studies by LaSalle have demonstrated the existence of a massive ancient landslide adjacent to the Shipshaw site. Earth movement resulting from this landslide could explain the presence of the organic stratum. Carbon-14 dating suggests a date for this landslide that agrees with historical records of the great Quebec earthquake of Aug. 1663. The 1663 earthquake induced earth movements greater than any other earthquake which has occurred in Canada since that time, supporting the possibility that it was the 1663 event which caused the unusual positioning of the organic deposits. References are given to two papers published in 1945 on the Shipshaw studies. Important corrections to conclusions contained in these papers are suggested.

● 3.6-28 **Data from selected accelerograph stations at Wilshire Boulevard, Century City, and Ventura Boulevard, Los Angeles, California,** Shannon & Wilson, Inc., and Agbabian Assoc., Seattle, Washington, and El Segundo, California, June 1978, 370.

Seismic and geotechnical data for eleven accelerograph stations located in three parts of Los Angeles are presented. Four stations each are situated near Wilshire Blvd. and Century City, and three stations are located on Ventura Blvd.

Near the Wilshire Blvd. stations, a 400-ft deep boring reveals that this region is underlain by about 30 ft of alternating layers of hard clays and dense sands. Below 30 ft, hard silty clay was found for the full depth of the boring. Five of six shallow borings drilled by others can be used to classify these materials as weathered rock (siltstones and shales). Seismic shear wave velocities of 2500 fps were determined below a depth of approximately 200 ft.

At Century City, the four accelerograph stations are underlain by interbedded layers of stiff to hard clays and silts and dense to very dense sands to a depth of about 80 ft. Between depths of 80 and 130 ft, a very dense sand was encountered with a shear wave velocity, increasing with depth, from 1000 to 2000 fps. Below 130 ft, the soil gradually grades with depth from a very dense, silty sand to a hard, sandy, clayey silt. Seismic shear wave velocities are about 2000 fps below 130 ft. At depths greater than 305 ft, these velocities reach 2500 fps.

At the Ventura Blvd. stations, the upper 65 ft of soil consist of interlayered dense sands and silts and stiff to hard clays. Below 65 ft to a depth of 320 ft, the materials are classified as either hard silty clays, clayey silts and sandy silts, or weathered fractured shale. The seismic shear wave velocities in these materials range between 1800 and 2300 fps below a depth of 150 ft.

Included along with the geotechnical data are descriptions of each accelerograph station, a discussion of the seismicity of each region, and a catalog of seismic events. Also, selected ground motion time histories and their corresponding response spectra are provided.

● 3.6-29 **Fault evaluation study: Marysville Lake project, Parks Bar alternate, Yuba River, California,** U.S. Army Corps of Engineers, Sacramento, California, May 1977, 32.

● 3.6-30 Der Kiureghian, A., **Seismic risk analysis including attenuation uncertainty,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 99-109. (For a full bibliographic citation see Abstract No. 1.2-3.)

Methods for seismic risk analysis are discussed. The effects of various uncertainties on seismic risk are compared, and it is shown that attenuation uncertainty is the most crucial of these. A general formulation for seismic risk analysis, including attenuation uncertainty, is presented and then applied to an actual site in San Francisco. Computed risks with and without attenuation uncertainty are compared and it is shown that the attenuation uncertainty has a highly significant effect on the calculated seismic risk.

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

● 3.6-31 Tsuchida, H. and Iai, S., **Observation of earthquake response of ground with horizontal and vertical seismometer arrays (2nd report)**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 22, Nov. 1978, 169-176.

A two-dimensional accelerometer array has been in operation at the Tokyo International Airport. Six accelerometers for recording two horizontal ground motion components are located every 500 m along a straight line on the ground surface. Two downhole accelerometers for recording three components are located at two points. The horizontal distance between the points is 2000 m. Depths of the downhole accelerometer locations are about 67 and 50 m. Three records from the array were selected and used to study seismic wave propagation in the surface layer. Frequency response functions were calculated for many combinations of two accelerometer points. It was found that the multiple reflection of shear waves in the vertical direction in the surface layer did not contradict the results of the analysis.

● 3.6-32 Katayama, T., **Engineering prediction of acceleration response spectra and its application to seismic risk analysis**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 8, Nov. 1978, 57-64.

A method of evaluating seismic risk in terms of acceleration response spectra is presented. The results of a study on the statistical analysis of the 277 acceleration response spectra obtained from Japanese strong-motion records are used as an attenuation law to relate the earthquake magnitude, distance, and site conditions to the nature of strong motion at a site. The method is applied to estimate the seismic risk of five randomly selected sites in Japan. The final output from the risk analysis for a site is in the form of the expected acceleration response spectra for different ground conditions at the site. The data for the seismicity of the area surrounding each site was obtained from the catalog of nearly 18,000 earthquakes that occurred in the vicinity of Japan in historical time.

● 3.6-33 **Auburn damsite–seismic studies overview**, Engineering and Research Center, U.S. Bureau of Reclamation, Denver, Colorado, July 1978, 39. (NTIS Accession No. PB 285 192)

The Aug. 1, 1975, Oroville earthquake which occurred about 45 miles north of the Auburn dam site required a reassessment of the seismic loading conditions for the Auburn dam site. This report presents the historical development of the seismic investigations for the Auburn dam site, a discussion of the problem posed by the Oroville earthquake in the Foothills fault zone, and the objectives and results of the investigations and the review process planned for determining the adequacy of the seismic loadings proposed for the site.

● 3.6-34 Wright, J. P. and Takada, S., **Earthquake relative motions for lifelines**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 56, Nov. 1978, 441-448.

For lifeline earthquake engineering, simple procedures are being developed for estimating earthquake-induced relative displacement and ground strain, taking into account the extent of the lifeline system and the site geology. Observed earthquake data are examined and the separation distance between points on the system is found to be an important parameter because of the dispersive nature of wave propagation in the ground.

● 3.6-35 Gulkan, P. *et al.*, **Earthquake evaluation for Altinkaya Dam** (Altinkaya baraji deprem degerlendirmesi, in Turkish with English summary), *Report No. 77-02,* Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, Turkey, 1977, 262.

A detailed investigation of the seismic parameters which must be taken into account in the design of Altinkaya, a gravity-arch dam to be built 37 km south of Bafra on the Kizilirmak River, is presented. A general discription is given of the investigations necessary to predict earthquake ground motions in an area being considered as a dam site. Using as input the geology and seismic history of the region where Altinkaya is to be constructed, a geodynamical study is made. The ground motion which may be expected in the area is defined in terms of an acceleration record and a design spectrum.

Stresses in the dam body under operating and critical load combinations are computed, followed by a dynamic analysis in which time integration and spectrum analysis results are given. Suggestions are made for the seismic instrumentation of the dam body and vicinity. The results of a comprehensive literature survey are given in the appendices. Attenuation relations and response spectra, and methods for their determination under different conditions, are discussed. Areas to consider in the static and dynamic finite element analyses of dams and technical information on the SAP IV computer code conclude the report.

● 3.6-36 Benvegnu, F. *et al.*, **Considerations on the safety of possible nuclear installations in northeastern Italy in relation to local seismotectonics**, *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III**, 823-833. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Seismotectonic investigations were conducted in northeastern Italy. An interpretation of the results is presented to aid in the design of nuclear installations. The

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

discussion concerns a definition of the maximum earthquake which may affect the area and an evaluation of the probability that a stronger event could occur. The event thus determined is assumed as a reference ground motion for possible nuclear installations in northeastern Italy. The risk of earthquake-induced nuclear accidents in the area is considered. It is concluded that nuclear installations in northeastern Italy should be considered as safe as installations in other regions, except in a few areas which are indicated.

● 3.6-37 Wilson, R. C., Warrick, R. E. and Bennett, M. J., **Seismic velocities of San Francisco bayshore sediments,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 1007-1023. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Data gathered from seven borings in the southern San Francisco bayshore area show that each of the three Quaternary geologic formations—Holocene bay mud, young (late Quaternary) alluvium, and older (mid-Quaternary) alluvium—has a characteristic set of soil types, geotechnical properties, and seismic wave velocities. The bay mud consists of soft, normally consolidated, estuarine, plastic silts, and fat clays with an average shear wave velocity of 80 m/sec (260 ft/sec). The young alluvium consists of well-graded sands and gravels deposited in alluvial fans, interbedded with poorly graded fluvial channel sands and stiff, over consolidated, nonplastic silts and lean clays deposited on flood plains between fans. For this unit, the average shear wave velocity is equal to 280 m/sec (920 ft/sec). The older alluvium is also composed of well-graded sands and gravels from alluvial fans, but has a higher degree of consolidation than the younger alluvium deposits and a higher average shear wave velocity, 550 m/sec (1800 ft/sec).

The seismic data further suggest that the compressional wave velocities are controlled primarily by the position of the water table rather than the soil type or degree of consolidation. The average compressional velocity of dry soil is about 800 m/sec (2620 ft/sec) versus 1800 m/sec (5900 ft/sec) for water-saturated soils. The shear wave velocities, on the other hand, are quite sensitive to change in soil type or consolidation, but show little variation across the water table. For Quaternary soils, therefore, one should not rely on Poisson's ratio to estimate V_s from measurements of V_p alone, but should measure shear wave velocity directly.

The major geotechnical factors controlling the shear wave velocity appear to be (1) the soil type, with coarse-grained soils having a consistently higher average shear wave velocity than fine-grained types; (2) the degree of consolidation, with the over consolidated silts and clays of the young alluvium having consistently higher than the normally consolidated silts and clays of the bay mud, and (3) the age, with a higher average shear wave velocity for the older alluvium than for the young alluvium.

● 3.6-38 Faccioli, E., **Response spectra for soft soil sites,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 441-456. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Spectral response characteristics of soft soil sites, taken from a set of strong-motion accelerograms from several countries of the Circum-Pacific Belt zone, are studied by regression analyses of the effects of magnitude and distance. Pseudovelocity response ordinates at 15 values of natural period and 0.05 damping and peak ground acceleration, velocity, and displacement are considered. It appears that current methods for predicting mean spectral shapes or spectral amplification factors do not account properly for important features of the spectra, such as the dependence of their narrow-band characteristics on distance and magnitude. As an alternative to the regression approach, reasonable approximations are obtained by random vibration theory with a Kanai-Tajimi power spectral density function to represent the ground velocity instead of the ground acceleration, as is commonly assumed.

● 3.6-39 Murphy, D. J. *et al.*, **Dynamic properties of hard glacial till,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 636-659. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A specialized sampling and testing program was developed and implemented to investigate the dynamic properties of a hard glacial till deposit on the southern shore of Lake Ontario. The site will support the foundations of a nuclear power plant.

Shear moduli were found to be influenced significantly by sample disturbance, stress history, stress system during consolidation, and the compressibility of the test equipment. Special precautions were taken to minimize sample disturbance and special efforts were undertaken to simulate the in-situ stress history. Tests were conducted on isotropically and anisotropically consolidated specimens to evaluate the effects of the stress system during consolidation on the dynamic properties of the till. Corrections were applied to the measured moduli to account for the effects of the compressibility of the test apparatus. The shear moduli obtained from this test program, within the shear strain range of 3×10^{-5} to 6×10^{-3} (in/in), were 3.5 to 4.5 times higher than shear moduli obtained from tests conducted using conventional test procedures. There was good agreement between the corrected shear moduli extrapolated to very low shear strains ($\gamma xy = 1.0 \times 10^{-6}$) and shear moduli obtained from field geophysical tests.

● 3.6-40 Nataraja, M. S., Wong, I. H. and Toto, J. V., **Liquefaction potential at an ocean outfall in Puerto Rico,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 685–703. (For a full bibliographic citation, see Abstract No. 1.2–11.)

In this paper, an ocean outfall is discussed that will extend 2600 ft into the Aguadilla Bay, at the northwestern corner of Puerto Rico. The proposed outfall will form the terminus of the Aguada-Aguadilla waste water system. The subsurface soils beneath the sea floor along some parts of the alignment consist of fine sands which may be susceptible to both earthquake-induced and ocean wave-induced liquefaction under certain conditions. The design earthquake for the outfall is a modified Mercalli intensity VII to VIII event, and the maximum wave height for the design hurricane is as high as 50 ft. This paper presents some of the soil dynamic considerations used in evaluating liquefaction potential beneath this four-ft diameter prestressed concrete pipe outfall. It was concluded, after performing simplified analyses, that liquefaction was not a potential problem. Therefore, no remedial measures were recommended.

● **3.6-41** Applied Nucleonics Co., Inc., **Summary of seismic assessment of underground and buried nuclear power plants,** California Energy Resources Conservation and Development Commission, Sacramento, Sept. 1977, 205.

This report is a preliminary assessment of the implications on earthquake engineering of siting underground nuclear power facilities. The study reviews the major problems of the seismic design of underground structures. It also contains seismic design criteria suitable as input to conceptual design and cost studies.

● **3.6-42** California Seismic Safety Commission SSC-LNG Committee, **Seismic safety of proposed liquid natural gas (LNG) facilities in California,** *SSC 76-02,* California Seismic Safety Commission, 1977, 51.

● **3.6-43** Arnold, P., **Seismic risk analysis with combined random and nonrandom earthquake occurrence,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3111, 1978, 513–520.

Evaluation of site seismicity is the first step in developing seismic design criteria for a proposed construction site in a seismically active area. The time of occurrence, the location, and the magnitude of future earthquakes, and the attenuation of ground motions with distance from the source represent major uncertainties in the assessment of the seismic hazard. The development and application of a straightforward and flexible procedure for quantitative evaluation of the seismic hazard associated with combined random and nonrandom earthquake occurrence processes are described. The proposed procedure uses the basic methodology originally suggested by Cornell and provides a logical framework for extending the classical seismic risk analysis technique to a class of prediction in evaluating site seismicity.

● **3.6-44** Marcuson, III, W. F., Krinitzsky, E. L. and Kovanic, E. R., **Earthquake analysis of Fort Peck Dam, Montana,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/21, 1977, 287–292.

This paper summarizes the work that the U.S. Army Corps of Engineers conducted on Fort Peck Dam; the dam is located in Montana, on the Missouri River. Geological and seismological investigations were performed to determine the design earthquake. Field investigations were performed to obtain samples and to evaluate the in-situ properties. The liquefaction potential of the dam was examined by means of cyclic triaxial tests, and static and dynamic analyses were conducted. Embankment response to a traveling seismic wave in the foundation was calculated. An analysis of stability comparing the calculated dynamic stresses and the dynamic strengths of the material was made. This assessment shows that the factor of safety against five percent strain is greater than one. Based on the study and engineering judgment, it is concluded that the dam is safe for the earthquake loadings considered possible.

● **3.6-45** Ferritto, J. M. and Forrest, J. B., **Siting structures in seismic liquefaction areas,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/9, 1977, 225–229.

Using available information on soil strength and earthquake ground motion, the authors developed a Monte Carlo technique to predict the probability of liquefaction. By use of site earthquake recurrence information, the probability that an earthquake will cause liquefaction may be determined. A criteria is proposed for the selection of a bridge site to limit damage from liquefaction.

● **3.6-46** Hoexter, D. F., Holzhausen, G. and Soto, A. E., **A method of evaluating the relative stability of ground for hillside development,** *Engineering Geology,* 12, *4,* Dec. 1978, 319–336.

A relative-stability analysis of land intended for development is necessary to identify areas of unstable or potentially unstable ground and to differentiate them from adjacent areas of stable ground. The purpose of such an analysis is to convey information on ground stability to planners, engineers and other concerned professionals who desire to put the land to its best possible use.

The method of relative-stability analysis presented in this paper requires initial preparation of a detailed engineering geologic map that delineates rock and soil units, as well as pertinent structural features such as faults, landslides, and bedding orientations. A relative-stability map is then derived from the engineering geologic map. The relative-stability maps identify stable and unstable areas in descriptive terms that are meaningful to planners, engineers, and others who are not professional geologists. Three broad units—stable, unstable, and potentially unstable areas—can be subdivided into more specific categories based on local geologic conditions and the various sources of instability. Examples of these categories are potential ground rupture within the zone of an active fault, expansive soil, an active deep or shallow landslide, a potential deep or shallow landslide, and stable bedrock. The expected engineering behavior of the materials representing each category is briefly outlined in the explanation for the relative-stability map. By employing specific classifications of this type, information is conveyed to serve as a base for preliminary land-use and engineering decisions. The method of relative-stability analysis is illustrated by examples from three areas in the San Francisco Bay region.

● 3.6-47 Chadwick, W. L., chmn., Committee on Environmental Effects of the United States Committee on Large Dams, **Environmental effects of large dams,** American Society of Civil Engineers, New York, 1978, 225.

The volume contains eleven papers. Of interest to earthquake engineers is the paper: *Survey of seismic activity associated with large dams,* by W. L. Chadwick. Also of interest are references regarding reservoir-related seismicity. The paper by Chadwick is not individually abstracted in this volume of the *AJEE.*

● 3.6-48 Kiremidjian, A. S. and Shah, H. C., **Seismic risk analysis for California State Water Project,** *Technical Report No. 33,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Oct. 1978, 253.

This report presents the seismic hazard as it concerns the California State Water Project. The Poisson model of earthquake occurrences was employed in the analysis and Bayesian methods were used to improve and update the estimates of the model parameters.

The risk of damage to power plants and pumping plants was assessed by examinations of the seismic hazard at each site and the seismic design criteria of each plant. It was determined that the design load level employed for the substructures and superstructures of power and pumping plants corresponds to a horizontal peak ground acceleration of 0.5 g. The probability of exceeding the design level of 0.5 g in one year or 50 years was computed for 23 pumping plants and six power plants. A similar approach was used in determining the risk to switchyard equipment designed for a horizontal peak ground acceleration of 0.2 g; this risk was found to be considerably greater than the risk to pumping and power plants.

● 3.6-49 Pikul, R. R., Wang, L. R.-L. and O'Rourke, M. J., **Seismic vulnerability of the Latham water distribution system: a case study,** *Seismic Vulnerability, Behavior and Design of Underground Piping Systems, Technical Report 7,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Sept. 1978, 33.

This case study applies state-of-the-art earthquake engineering techniques plus the results of current research developed during the SVBDUPS Project to assess the potential vulnerability to earthquakes of the distribution piping system of the Latham Water District, Albany County, New York. The Latham Water District was considered typical of existing water distribution systems which have different types of pipe and joint systems reflecting the historical development of the service areas and the technology existing at the times of expansion.

This study indicates that a substantial portion of the water district could experience earthquake-related failures based on a 100-year economic lifetime and a 450-year return period earthquake (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 300-350 ft in some areas. In addition, distribution piping in this area is of a relatively non-flexible leadite or lead joint construction resulting in potential leakage under tensile forces. Introduction of flexible joint systems for new portions of the system as well as replacement of damaged older portions tends to continually upgrade the system and decrease vulnerability.

● 3.6-50 McGuire, R. K. *et al.*, **Probabilistic procedures for assessing soil liquefaction potential,** *Journal of Research,* 19, 1978, 38.

The probability of liquefaction at a site on Tokyo Bay is assessed by three methods. The empirical method uses only observations of liquefaction during prior earthquakes and does not account for soil strength. The surface acceleration method estimates layer shear stresses as a function of ground acceleration at the surface and determines the liquefaction hazard by comparing these shear stresses to shear strengths estimated from geotechnical surveys at the site. The direct load-resistance comparison method estimates layer shear stresses, given the magnitude and distance of the earthquake, and compares these to estimated shear strengths to determine liquefaction hazard. The first two methods indicate a probability of liquefaction at the site of 0.06 to 0.08 per year, which is consistent with the high historical seismicity around Tokyo Bay. Although the

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third method is thought to be the most direct and consistent method of accounting for the liquefaction potential caused by large, distant earthquakes which cause long durations of shaking, no reliable results were obtained by use of the method because of the few available strong-motion records on rock.

● 3.6-51 Ishihara, K., Silver, M. L. and Kitagawa, H., **Cyclic strengths of undisturbed sands obtained by large diameter sampling,** *Soils and Foundations,* **18**, *4,* Dec. 1978, 61-76.

At a site near the Shinano River in Niigata, Japan, where signs of liquefaction were conspicuous following the 1964 Niigata earthquake, a sand sampling program was carried out using a large diameter sampler to obtain undisturbed sand specimens for laboratory cyclic triaxial testing. The specimens were drained and frozen at the test site and brought back to the laboratory where they were again saturated and consolidated in the triaxial chamber to reproduce the in-situ state of stress without destroying the fabric of the sand. Cyclic loading tests were then performed and the resistance to liquefaction was determined for specimens obtained from depths 2.5 m through 11.5 m deep. The result of these tests showed that the cyclic strengths of undisturbed loose sands from the test site were somewhat lower than would be anticipated from the similar cyclic triaxial tests performed on reconstituted specimens of similar clean sands.

● 3.6-52 Schaefer, S. F. and Herrmann, R. B., **Seismic risk analysis applied to the central United States,** *Earthquake Notes,* **48**, *4,* Oct.-Dec. 1977, 35-43.

The method of engineering seismic risk analysis developed by Cornell is applied to the central United States to estimate the risk of exceeding a given intensity due to earthquakes in and near the New Madrid seismic zone. The intensities associated with a 50-year risk of 10% are plotted for three different assumptions of source distribution. The implications of these assumptions are discussed in detail. Site specific risk estimates are presented for four cities in the region: St. Louis, Missouri; Memphis, Tennessee; Cape Girardeau, Missouri; and Evansville, Indiana. While the results may be conservative due to the assumed attenuation law, the results serve as a guide in making decisions concerning seismic risk.

● 3.6-53 **Composite vulnerability analysis: a methodology and case study of the Metro Manila area,** rev. technical report, United Nations, Office of the Disaster Relief Coordinator, Geneva [1978], 59.

● 3.6-54 **Geotechnical and strong motion earthquake data from U.S. accelerograph stations: Pasadena (CIT Millikan Library), Santa Barbara County Court House, Taft (Lincoln School Tunnel) and Hollister (Melendy Ranch Barn), California,** Shannon & Wilson, Inc., and Agbabian Assoc., Seattle, Washington, and El Segundo, California, June 1978, Vol. 2, 164.

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4. Strong Motion Seismometry

4.1 Instrumentation

● **4.1-1** Brekke, T. L. and Korbin, G. E., **Seismic instrumentation of transportation tunnels in California,** *FHWA-RD-77-138,* Aug. 1977, 26. (NTIS Accession No. PB 275 457)

This study was initiated during the spring of 1977 as a part of a more comprehensive program on the response of tunnels to earthquakes. The objective was to provide guidance for an early installment of relatively simple instrumentation in a few selected tunnels in California. The report is composed of three parts. The first part describes suggested instrumentation programs at four different levels of sophistication. For the initial program, it is foreseen that the first two levels of instrumentation will be employed. The more sophisticated programs have, however, been included to give an appropriate reference frame for the instruments to be installed and to provide guidance for possible future installations.

The second part lists the criteria used in selecting tunnel sites. The final part describes the tunnels chosen and discusses the geological environment and the tunnel support systems. The candidate tunnels are (1) Loleta Railroad Tunnel, No. 40, Humboldt County; (2) Caldecott Tunnels, Alameda County; and (3) San Fernando Railroad Tunnel, No. 25, Los Angeles County.

● **4.1-2** Pletnev, K. G. and Fremd, V. M., **Instrumental observations in epicentral zones,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-14, 1978, 99-105.

Instrumentation requirements are stated for seismic observations in epicentral zones of strong earthquakes. A set of seismographs is proposed to provide adequate recordings in broad frequency ranges. The seismic networks in Daghestan (1970) and Gazlii (1976) near fields are considered. Some results of these observations are given.

● **4.1-3** Petrovski, J., **Need for experimental evidence in development of seismic microzoning methods,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 413-420.

Existing empirically developed seismic microzoning methods and proposed methods for development of seismic design parameters are discussed. Experimental data is needed to construct mathematical models and analytical techniques and to validate existing methods. A three-dimensional dense instrumentation array for recording ambient and forced vibrations resulting from small and large earthquakes has been developed for this purpose.

● **4.1-4** Negmatullaev, S. Kh. *et al.,* **Engineering and seismological observations at dams,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 681-691.

Seismological studies of dams must investigate the pre-impounding seismic regime and monitor any changes in seismicity during and after filling of the reservoir. Engineering seismological studies must investigate the kinematics of ground motion in and around the dam during earthquakes, the dynamic stresses and pore pressures within the body of the dam, and any residual deformation. Depending upon the size of the dam and the seismic hazard, three levels of investigation are recommended: (1) for dams less than 100

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m high in areas of low seismicity, continuous operation of 1 to 3 seismograph stations in the reservoir region and 1 or 2 strong-motion instruments on or near the dam; (2) for dams more than 100 m high in areas of moderate to high seismicity, continuous operation of 4 to 6 seismograph stations around the reservoir and 4 to 6 sets of instruments for measuring strong-motion, stress, pore pressure, and residual deformation within the dam; (3) for dams of special interest, such as the 315 m high earthfill Nurek Dam in Tadjikistan, continuous operation of more than 6 seismograph stations around the reservoir including at least 5 years of pre-impounding monitoring, and a more complete complex of instruments for measuring strong-motion and stress deformation conditions within the dam.

● **4.1-5** Basarir, E., **Some principal methods of instrumental seismology and applications** (Aletsel sismolojide bazi ana yontemler ve uygulamalar, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **5**, *17*, Apr. 1977, 53-95.

Basic methods in the field of instrumental seismology are considered and applied to the instruments at the Kandilli Observatory, especially seismograph systems, and their calibration techniques. This study does not examine systems which include a galvanometer. The effect of the damping factor of long-period seismograph systems on critical damping is calculated. For this purpose, several seismograms obtained at different times were investigated and it was found that there was disagreement in the calculated damping factors. It is concluded that the differences are due to noise and digitizing errors.

A seismometer transfer function was evaluated numerically for various damping factors and natural frequencies were calculated by computer. Impulsive responses were computed using an inverse fast Fourier transform. Calibration methods were also applied to the Istanbul Kandilli Observatory short-period geotech seismograph systems to find the damping factor, the natural frequency, the electromotor constant of the seismometer, and the sensitivity. It was found that various system constants could vary considerably from the values given in the manual. These results show the necessity of calibrating the systems at least once a year.

● **4.1-6** Goto, N. and Okada, S., **A proposal for renewal of strong motion observation by use of SMAC accelerograph** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 43, Nov. 1978, 337-344.

The SMAC-type accelerograph, installed in more than 1000 locations in Japan, has provided a number of records valuable for engineering purposes in the last 20 years. However, high-quality strong-motion seismograms are needed for earthquake engineering purposes. The recording amplitude coverage of the SMAC accelerograph is insufficient, especially in the period range beyond 1 sec, because the accelerograph is not sensitive in this range. In addition, only 1-sec intervals can be timed with the accelerograph. This paper proposes the use of a digital recording system and a crystal clock time coding system to improve the accelerograph. Overall frequency characteristics and the amplitude resolution capability of this system are examined by means of a shaking table test and by observation of volcanic earthquakes.

● **4.1-7** Cervellati, R., **Experience on the performance of CNEN seismic instrumentation in Friuli**, *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations*, **Vol. II**, 244-261. (For a full bibliographic citation, see Abstract No. 1.2-7.)

The Italian Comitato Nazionale Energia Nucleare intervened in Friuli soon after the main shock in the spring of 1976. The agency placed strong-motion accelerometers, seismometers, and recording instrumentation in the epicentral region. After a description of the experimental setup, the advantages and limitations of the present instrumentation are discussed. Present trends concerning the instrumentation of the mobile laboratory are illustrated.

● **4.1-8** Cervellati, R. and Rienzo, G., **Calibration of strong-motion accelerometers Kinemetrics SMA-1**, *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations*, **Vol. II**, 262-305. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Calibration measurements are performed on two SMA-1 accelerometers of the same type used during the 1976 Friuli earthquake. The purpose is to verify the behavior of the sensors in known conditions. Experiments are carried out on amplitude and phase response versus frequency, linearity, and the response of the accelerometers to motion with known time dependence. Static tests are performed to check sensitivity. Tests are also conducted to control the vertical trigger threshold of the accelerometers.

● **4.1-9** Long, R. E., **Specification of instrumentation for estimating and monitoring ground motion from earthquakes**, *Instrumentation for Ground Vibration and Earthquakes*, Proceedings of the Conference of the Society for Earthquake and Civil Engineering Dynamics, Institution of Civil Engineers, London, Paper 8, 1978, 85-90.

This paper reviews some of the problems facing a civil engineer required to specify a program giving pre- and post-design data for assessing the effects of seismic ground motion. Some solutions to these problems as they affect seismic instrumentation are discussed.

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● **4.1-10** Willmore, P. L., **Recording earthquakes,** *Instrumentation for Ground Vibration and Earthquakes,* Proceedings of the Conference of the Society for Earthquake and Civil Engineering Dynamics, Institution of Civil Engineers, London, Paper 1, 1978, 1-10.

Earthquakes and man-made vibrations have very different causative mechanisms, but the seismographs used for recording in the near-field are almost all of the "pendulum" class. Such seismographs can be described by a single equation of motion with two adjustable parameters. The fundamental distinctions between the two major classes of instruments reside almost entirely in the recording systems: earthquakes and unplanned explosions require continuous or automatically triggered recording, while vibrations and planned explosions can be sampled at will. Variations in performance which can be built into this simple framework are discussed, and some introductory comments on later contributions to the symposium are included.

● **4.1-11** Latham, G. *et al.,* **The Texas ocean-bottom seismograph,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. III, OTC 3223, 1978, 1467-1476.

A low-cost seismic station for use on the ocean bottom at virtually any depth has been developed by the Marine Science Inst. (Geophysics Lab.) of the Univ. of Texas at Austin. Through the use of sophisticated micropower integrated circuits operating near the limits of the present state of the electronic art, and through the use of event-triggered data recording, it has proved possible to construct a system whose cost and operating power consumption are very low when compared with what has been possible for systems of earlier design. In particular, these factors, low cost and low operating power, make possible the deployment of ocean-bottom seismic networks capable of continuous operation for periods up to several months at a cost that is quite low in terms of the potential scientific return. Twenty stations have been constructed, and they have been deployed at 80 locations during the past 18 months for both refraction and earthquake experiments. In these experiments, water depths ranged from 60 m to 6400 m, and bottom time ranged from a few hours to 53 days. Successful recoveries were made in 75 cases. Based on the results of these experiments, criteria have been developed for improved ocean-bottom seismic systems, and new systems capable of much more sophisticated data acquisition and storage are under development.

4.2 Regional Data Collection Systems

● **4.2-1** Baumgartner, G. and Sagesser, R., **A concept for strong motion instrumentation in Switzerland based on seismic risk considerations,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-12, 1978, 87-94.

Instrumental records of strong earthquakes in Europe are sparse and for some countries nonexistent. In Switzerland, a dense microtremor network is successfully operated by the Swiss Earthquake Service; however, a strong-motion system has not yet been established. With the development of seismic risk maps for Switzerland, it is possible to design a seismic network taking into account regional seismotectonic characteristics and maximum instrumental yield. It is shown that data expectance from a minimal strong-motion network can be satisfactory—even for a country of moderate seismicity—if seismic risk considerations are employed in network design.

● **4.2-2** Denisov, B. E. *et al.,* **Some problems of engineering-seismometric service organization and instrumental information processing,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-13, 1978, 95-98.

● **4.2-3** Hart, G. C. and Rojahn, C., **Selection of buildings for strong-motion instrumentation using zonation information and decision theory,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1135-1144.

Decision theory is used to determine which buildings should be given first priority for instrumentation in the various seismically active areas of California. The expected severity at each location of ground shaking and its probability of occurrence can be defined in terms of peak acceleration, modified Mercalli intensity, earthquake magnitude and epicentral distance, or some other measure of strong ground shaking. Building classes must be identified, and the value of obtaining a building response record for each building type can be quantified according to professional engineering judgement. Using this information, decision theory can be used to calculate the expected value of instrumenting buildings of a particular class at various locations. The locations are then ranked in order of preference for each building class. This procedure can be extended to instrumentation programs in other regions.

● **4.2-4** Yokoyama, Y. and Kurata, E., **Site characteristics of strong-motion earthquake stations in ports and harbours in Japan (Part IV)** (in Japanese), *Technical Note 298,* Japan Port and Harbour Research Inst. [Yokosuka], June 1978, 110.

The strong-motion earthquake network in Japanese port areas consisted in Mar. 1978 of 69 stations in 46 ports. This report presents site data on 16 newly installed stations and 4 relocated stations in the period 1972-1978. The site

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data for each station includes maps which show instrument location, geological condition, and structures around the station; figures of instrument foundation and housing; and a boring log.

● 4.2-5 Matthiesen, R. B., **On the development of strong-motion instrument networks in the United States,** *Open-File Report 78-1024,* U.S. Geological Survey, Menlo Park, California, Oct. 1978, 91.

This report outlines a plan for the distribution of strong-motion instrumentation throughout the United States. The present national network of strong-motion instrumentation originated through a merger of the programs of several agencies and organizations with objectives ranging from research to regulation. The network is the result of the coordination of instrument maintenance and record archives currently provided by the Seismic Engineering Branch of the U.S. Geological Survey which operates with funds from the National Science Foundation in cooperation with other federal, state, and local agencies. NSF supports data management and the operation of a network of about 200 accelerographs and 300 seismoscopes utilized for studies of ground motion and building response. The State of California is developing its own strong-motion instrumentation program (CSMIP), which includes measurements of ground motion and the response of representative types of structures. The CSMIP network is the largest network operated by a single agency anywhere in the world and eventually will contain a total of about 1000 accelerographs. The Army Corps of Engineers is developing a program for monitoring the response of earth dams, which eventually will include as many as 400 instruments on more than 100 dams. Several other organizations also are developing networks appropriate to their specific objectives.

● 4.2-6 Navarro, R., Wuollet, G. M. and Bradley, B. R., **Catalog of seismograph stations operated in support of the ERDA/Nevada operations office, January 1964 thru June 1976,** *Open-File Report 77-404,* U.S. Geological Survey, Las Vegas, Nevada, May 1977, 76.

This catalog lists seismograph stations established during the period from Jan. 1964 through June 1976 in support of the Energy Research and Development Admin., Nevada, underground weapons testing program at the Nevada Test Site in central Nevada and at Amchitka, Alaska. Given for each station are location by coordinates, elevation, site soil medium, and whether the station site is on natural terrain or a concrete surface.

● 4.2-7 Wittlinger, G., Holl, J. M. and Ball, G., **A telemetered 7 stations seismic-network for near field study** (in French), *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. II,** 225-243. (For a full bibliographic citation, see Abstract No. 1.2-7.)

A seismological network has been designed to record the seisms in the epicentral area of the Friuli earthquake. The main qualities required of the network are equipment mobility and strength; the collection of data of good quality that would allow direct numerization for an elaborated signal treatment; maintenance simplicity and reduced operating costs. These considerations have led to the devising of a 7-station telemetered network with a central receiving and recording station. The seismological stations are of small weight and take up a small space. They consume a low amount of electricity. The central station is equipped with a triggered numerical recording set.

● 4.2-8 Browitt, C. W. A., **Detection and location of earthquakes and unplanned explosions,** *Instrumentation for Ground Vibration and Earthquakes,* Proceedings of the Conference of the Society for Earthquake and Civil Engineering Dynamics, Institution of Civil Engineers, London, Paper 6, 1978, 63-72.

An understanding of the principles of seismic source location leads to the development of a seismograph network strategy for detecting seismic waves and determining focal parameters. The value of the macroseismic method is discussed.

● 4.2-9 Bolt, B. A., Okubo, P. and Uhrhammer, R. A., **Optimum station distribution and determination of hypocenters for small seismographic networks,** *Misc. Paper S-78-9,* Geotechnical Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1978, 43.

Design of an optimal network of seismographs around a large reservoir to locate nearby earthquakes presents a number of theoretical and practical problems. This study discusses the goals of such networks and sets out general guidelines for network design to achieve these goals. The underlying variational problem is how to minimize and distribute the number of stations in order to achieve a desired level of precision in earthquake detection and hypocentral location. It is shown that a joint location method provides optimal solutions for clusters of earthquake hypocenters within a local network. A special FORTRAN program, called GHYP1, was written to do this joint reduction with simultaneous estimation of station adjustment terms. Sensitivity analyses for representative crustal models and network patterns provide guidelines for achievable hypocentral uncertainties.

The problem of location of reservoir-associated seismicity is part of a more general inverse problem in which properties of the matrices of condition provide not only the variances and covariances of the estimates, but also indicate the sensitivity of the solution to changes in azimuths and distances of stations relative to the earthquake cluster. The mean seismic velocities in the rock layers under the reservoir can also be determined simultaneously with a tradeoff between the resolution of the velocity estimates and their statistical uncertainties. Where possible, the type of seismograph and analysis system chosen should provide readings of both P and S phases for use in the matrix inversions.

Two specific cases of earthquake sequences located near reservoirs in California are analyzed in detail using GHYP1: Oroville 1975 and Briones Hills 1977. A full explanation is given of the input and output expected for this joint location method. The program is suitable for routine use.

● **4.2-10** Alvarez, S. J., **A proposal for improvement of seismographic network system in El Salvador,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* 14, Dec. 1978, 19-30.

A technique to evaluate a seismographic network is derived and applied to the seismographic station operation in El Salvador. It is concluded that for earthquakes of smaller magnitudes hypocentral control is poor in the northeastern part of the country. Various ways are examined in this paper to improve this situation and to increase the capacity of entire networks.

● **4.2-11** Bollinger, G. A. and Murphy, C. A., comps., **Seismicity of the southeastern United States, July 1, 1977-December 31, 1977,** *Bulletin No. 1,* Dept. of Geological Sciences, Virginia Polytechnic Inst. and State Univ., Blacksburg, Apr. 1978, 56.

This report, the first in a semiannual series, contains a tabular listing by state of the 53 stations operating during the period from July to Dec. 1977. 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 and an appendix giving general station information and magnification curves.

The report also contains a listing 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. Included is an epicenter map for the July 1 to Dec. 31, 1977, period. Fifty-five earthquakes were detected during that time. Areas of multiple occurrences of microearthquakes are indicated.

● **4.2-12** Bollinger, G. A. and Mathena, E., comps., **Seismicity of the southeastern United States, January 1, 1978-June 30, 1978,** *Bulletin No. 2,* Dept. of Geological Sciences, Virginia Polytechnic Inst. and State Univ., Blacksburg, Nov. 1978, 78.

This report contains a tabular listing by state of the 62 stations operating in the southeastern United States during the period from Jan. to June 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 and figures showing the South Carolina; Giles County, Virginia; and Wallace Dam, Georgia, networks. Since each of these networks has station spacings too close to be shown clearly on the map, 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 United States 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.

There were 17 earthquakes detected and located during the report period. In addition, extensive microseismicity was reported for South Carolina, particularly at Lake Jocassee, Lake Keowee, and Monticello Reservoir. Extensive microseismicity was also reported for central Georgia. Also included in the report are an epicenter map for the report period and a cumulative epicenter map for the July 1, 1977, through June 30, 1978, period.

● **4.2-13** Porcella, R. L., **Strong-motion instrumentation in the central and eastern United States,** *Earthquake Notes,* 49, 2, Apr.-June 1978, 3-14.

The strong-motion instrumentation network operated by the U.S. Geological Survey (USGS) in cooperation with other agencies in the central and eastern United States consists of approximately 140 triaxial accelerographs located at 68 stations in 25 states east of the Rocky Mountains. This network is largely the result of programs of the U.S. Army Corps of Engineers (COE) to monitor strong ground shaking and structure response at COE dams and the Veterans Administration (VA) to measure base motions of large hospital buildings. In addition, the National Science Foundation (NSF) is supporting the USGS in development of accelerograph networks to obtain ground motion measurements in seismically active areas. Other organizations, including the Lamont-Doherty Geological Observatory (LDGO) and numerous power utilities with nuclear generating units, have established small strong-motion arrays in this region. More than a dozen accelerograms have been recovered from instrumentation in the central and eastern United States since LDGO obtained the first of several records from a series of northern New York earthquakes in July-Aug. 1973. The maximum reported acceleration (0.076 g) for this region was recorded during the New Madrid earthquake of June 13, 1975 (magnitude 4.3) at an epicentral distance of about 10 km. As a result of recent studies of the recurrence of strong ground motion, the USGS will install about 36 accelerographs in the New Madrid seismic zone; this instrumentation will comprise a grid network with station spacings ranging from 10 to 25 km. The primary objective of the network, which is supported by NSF, is to obtain data for use in the investigation of the spectral characteristics and attenuation of strong ground motion.

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5. Dynamics of Soils, Rocks and Foundations

5.1 General

● **5.1-1** Kinoshita, S., **Simple method for formulating the wave transfer function and its application to deep and shallow borehole data,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 18, Nov. 1978, 137-144.

A closed-form solution for a wave transfer function is presented. The equal-time layered model is used to obtain the predominant frequencies and the equivalent damping factors. The equivalent damping factor is distinguished from the quantities resulting from the effects of diffusive damping and internal damping. The theoretically derived transfer function is compared with the results calculated from observed data.

● **5.1-2** Stokoe, K. H. and Hoar, R. J., **Variables affecting in situ seismic measurements,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 919-939. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Variables which can affect the accuracy of in-situ compression and shear wave velocity measurements by the crosshole and downhole seismic methods are discussed. Components for accurate field measurements include mechanical sources such as strong, directional, and repeatable shear wave generators; receivers with proper coupling, orientation, and frequency response; recorders with accurate timing and proper frequency response; precise and consistent triggering systems; and well-trained personnel. Wave velocity measurements are also affected by soil disturbance, type of borehole and array, and data collection and analysis procedures. In general, the most significant errors result from improper triggering, borehole disturbance and casing effects, and the lack of vertical borehole measurements. Added together, these variables can cause errors greater than 100% in measured wave velocities. A data collection procedure employing interval travel times with trigger and channel delays which minimizes these errors is presented.

● **5.1-3** Asada, A., **Input seismic motion for the use in soil dynamics,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/1, 1977, 179-182.

This paper compares observational and theoretical results in an attempt to determine whether shear waves or surface waves have more influence on seismic ground motion. It is concluded that it is as important to use the horizontal component of a dispersive Rayleigh wave or a Love wave in soil dynamics as it is to adopt an SH-wave as the horizontal input component. The vertical component of the input wave that should be adopted is not the P-wave but the vertical component of the dispersive Rayleigh wave, the amplitude of which is greater than that of the P-wave. In the earthquake response analysis of structures long in the axial direction and resting either on or in the ground (such as pipelines and dikes), it is necessary to evaluate the deformation in proportion to the velocity amplitude which is dependent upon the time lag produced by the propagation of surface waves.

● **5.1-4** Lysmer, J., **Analytical procedures in soil dynamics,** *UCB/EERC-78/29,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1978, 98.

The 1978 state-of-the-art of soil dynamics analysis is reviewed. A classification system is suggested for soil dynamics response problems, and a discussion is given of the current ability and future possibilities for solving different types of problems. Special attention is given to the possibilities for nonlinear and effective stress analysis of

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seismic problems. Major topics discussed are foundation vibrations, pile vibrations, seismic site response problems, and soil-structure interaction.

5.2 Dynamic Properties of Soils, Rocks and Foundations

● 5.2-1 Ohta, Y. *et al.*, **Shear wave velocity measurement during a standard penetration test,** *Earthquake Engineering and Structural Dynamics*, **6**, *1*, Jan.-Feb. 1978, 43–50.

An experiment was carried out to develop a technique for measuring shear wave velocity simultaneously with the standard penetration test. In this test, an impact at the bottom of a borehole is produced by weight dropping, which may generate seismic waves. A three-component geophone was placed on the ground surface near the borehole, and the waves were recorded with a magnetic recorder at successive depths of penetration. The predominance of SV waves obtained with this method was assured by measurement of the particle orbit.

Since signal amplitudes decrease with depth and become less than the noise level at a certain depth, records from deeper sources must be processed to disclose the shear waves. Because waveforms of SV events generated by blows of the penetration test at a given depth are very similar, it is expected that the signal-to-noise ratio would be improved by a stack of wave trains. A pasteup of the radial component after stacking was compared with that before stacking, and a refinement was clearly recognized. A vertical distribution of shear wave velocity was obtained by reading the onset time at each depth. The results were compared with N values from the standard penetration test and specific resistivities from electrical logging in the same borehole. The data were mutually consistent. This experiment showed that a convenient, precise shear wave velocity measurement can be conducted during the routine work of a standard penetration test.

● 5.2-2 Ohta, Y. and Goto, N., **Empirical shear wave velocity equations in terms of characteristic soil indexes,** *Earthquake Engineering and Structural Dynamics*, **6**, *2*, Mar.-Apr. 1978, 167–187.

An investigation to systematize empirical equations for the shear wave velocity of soils was made in terms of four characteristic indexes, *N*-value of the standard penetration test, depth where the soil is situated, geological epoch, and soil type. As some of these indexes are variates belonging to interval scales, while others belong to nominal or ordinal scales, the technique known as multivariate analysis cannot be employed. A new approach to the theory of quantification, after C. Hayashi, was introduced and developed for solving this difficulty.

Fifteen sets of empirical equations to estimate low-strain shear wave velocity theoretically may be obtained by combining the four indexes. All these sets were derived by use of about 300 data, and their accuracies were evaluated by means of correlation coefficients between the measured and estimated shear wave velocities. The best equation included all the indexes; its correlation coefficient was 0.86. The empirical equation relating the standard penetration *N*-value to the shear wave velocity provided a correlation of only 0.72, and is one of the lowest ranking among the 15 sets of equations.

● 5.2-3 Taylor, P. W. and Larkin, T. J., **Seismic site response of nonlinear soil media,** *Journal of the Geotechnical Engineering Division, ASCE*, **104**, *GT3*, Proc. Paper 13597, Mar. 1978, 369–383.

A procedure for the analysis of site response to earthquakes, assuming vertical, one-dimensional shear wave propagation, is presented. The procedure entails: the determination of low-amplitude soil moduli from in-situ shear-wave velocity measurements; the determination of the modulus/strain amplitude relationship for each soil type using free vibration torsion tests; the correction of these results for sample disturbance; and the determination of nonlinear soil parameters for use in a lumped-mass site response analysis. The use of a hysteretically damped nonlinear soil model in the analysis is described in detail. Although limited by the constraints of the assumption of vertical, one-dimensional shear wave propagation, the method is believed to simulate actual soil profile behavior more closely than other models currently in use.

● 5.2-4 Seed, H. B., Pyke, R. M. and Martin, G. R., **Effect of multidirectional shaking on pore pressure development in sands,** *Journal of the Geotechnical Engineering Division, ASCE*, **104**, *GT1*, Proc. Paper 13485, Jan. 1978, 27–44.

The effect of multidirectional shaking on the liquefaction of saturated sands is estimated using: (1) the results of multidirectional shaking table tests to measure the settlement of dry sands and (2) a model of the mechanism of liquefaction of saturated sands that uses data obtained in cyclic simple shear tests on dry sands. It is shown that excess pore pressures may develop twice as fast under two equal horizontal components of motion than under a single component, but that a reduction of only 10% in the shear stresses causing liquefaction is normally adequate to account for the effect of multidirectional shaking in analyses of liquefaction potential.

● 5.2-5 Dasgupta, S. P. and Kameswara Rao, N. S. V., **Dynamics of rectangular footings by finite elements,** *Journal of the Geotechnical Engineering Division, ASCE*, **104**, *GT5*, Proc. Paper 13763, May 1978, 621–637.

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A finite element solution in three dimensions for rectangular footings resting on a soil medium has been presented for the vertical mode of vibration. The soil medium has been idealized as an elastic halfspace. Both linear and nonlinear as well as depth-dependent soil properties have been considered for analysis. For discretizing into a finite number of elements, the semi-infinite elastic medium is idealized as a bounded region by adopting appropriate boundary conditions. A simple hexadedron isoparametric element with eight nodes (ZIB8) has been taken as the basic element. Experimental and analytical studies indicate that the nature of contact pressures at the footing-soil interface changes with the magnitudes of operational frequencies; thus all probable contact pressures have been incorporated in the analysis. Effects of embedment, static surcharge, nonhomogeneity, and nonlinear stress-strain characteristics are shown, and the influence of these factors on the resonant fequencies are examined. Results are compared with the existing solutions and presented graphically.

● 5.2-6 Mori, K., Seed, H. B. and Chan, C. K., **Influence of sample disturbance on sand response to cyclic loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT3,* Proc. Paper 13594, Mar. 1978, 323–339.

The factors influencing the cyclic liquefaction characteristics of saturated sands are reviewed and shown to be profoundly influenced by the relative density, the sand structure, a prolonged period of pressure application, the past seismic history, and the effects of overconsolidation. A study is described in which the cyclic liquefaction characteristics of samples extracted carefully from a bed of sand having a prior seismic history are determined and compared with the characteristics of samples from an otherwise identical bed having no seismic history. Although the sand beds had characteristics differing by 50%, the characteristics of samples taken from both beds were essentially the same. It is suggested that the effects of many factors affecting the stability of natural deposits of dense clean sand are lost during the sampling process and that special care is required to arrive at a reasonable evaluation of the cyclic liquefaction characteristics of such soils.

● 5.2-7 Novak, M. and Aboul-Ella, F., **Impedance functions of piles in layered media,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM3,* Proc. Paper 13847, June 1978, 643–661.

An approximate analytical solution is established that makes it possible to calculate impedance functions (stiffness and damping) of a single pile embedded in layered media. The pile can be of stepwise variable cross section and feature any tip condition. The impedance functions are complex and frequency dependent but can be obtained by means of a computer program. A comparison with experiments indicates the potential of the theory and demonstrates the need to consider the variation of soil properties wtih depth and the lack of fixity of the tip for short piles.

● 5.2-8 Vinson, T. S., Chaichanavong, T. and Czajkowski, R. L., **Behavior of frozen clays under cyclic axial loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT7,* Proc. Paper 13902, July 1978, 779–800.

The dynamic Young's modulus and damping ratio were determined for axial strain amplitudes from 3×10^{-3}% to 10^{-1}%, temperatures from 30.2°F to 14°F (-1°C to -10°C), frequencies from 0.05 cps to 5 cps, and confining pressures from 0 psi to 200 psi (kN/m^2 to 1,380 kN/m^2). For samples of the frozen Ontonagon clay, the value of dynamic Young's modulus over the range of test conditions was from 50×10^3 psi to 870×10^3 psi (3.45×10^3 kN/m^2 to $6,000 \times 10^3$ kN/m^2); the value of damping ratio was from 0.02 to 0.3.

The test results indicate that the dynamic Young's modulus of frozen clay decreases with increasing strain amplitude and specific surface area; it increases with descending temperature and increasing water content and frequency. The damping ratio increases with increasing strain amplitude and ascending temperature and decreases, in general, with increasing frequency. There appears to be no well-defined relationship between the damping ratio and the specific surface area or water content. The dynamic Young's modulus and damping ratio are apparently not affected by the confining pressure.

● 5.2-9 Vinson, T. S. and Chaichanavong, T., **Dynamic behavior of ice under cyclic axial loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT7,* Proc. Paper 13903, July 1978, 801–814.

The dynamic Young's modulus and damping ratio were determined for axial strain amplitudes from 3×10^{-3}% to 2×10^{-2}%, temperatures from 30.2°F to 14°F (-1°C to -10°C), frequencies from 0.05 cps to 5.0 cps, and confining pressures from 0 to 200 psi (0 kN/m^2 to 1,380 kN/m^2. The value of the dynamic Young's modulus over the range of test conditions was from 340×10^3 psi to 900×10^3 psi ($2,350 \times 10^3$ kN/m^2 to $6,200 \times 10^3$ kN/m^2); the value of damping ratio was from 0.02 to 0.11. The test results indicate that the dynamic Young's modulus of ice increases with increasing confining pressure and frequency and decreases with ascending temperature and strain amplitude. The damping ratio of ice appears to decrease as frequency increases from 0.05 cps to 1.0 cps and increases as frequency increases from 1.0 cps to 5.0 cps. The damping ratio appears to decrease with descending temperature and increase with increasing strain amplitude. There appears to be no well-defined relationship between the damping ratio of ice and the confining pressure.

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● **5.2-10** Mostaghel, N. and Habibagahi, K., **Cyclic liquefaction strength of sands,** *EEC 78-1, Report No. 3,* Earthquake Engineering Center, Pahlavi Univ., Shiraz, Iran, Jan. 1978, 52.

Through an energy approach, a model is proposed to predict the cyclic liquefaction strength of saturated sands in terms of their static shear strengths. Plots of cyclic liquefaction strength versus both relative density and 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 and compare favorably with Seed's empirical correlations.

● **5.2-11** Sherif, M. A. and Ishibashi, I., **Soil dynamics considerations for microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 81–110.

Microzonation for earthquake effects involves the determination of relevant site characteristics and their incorporation into land-use planning and the design of earthquake-resistant structures to reduce damage to human life and property in the event of an earthquake. The behavior of soils plays an important role in the microzonation of regions for earthquake effects. In considering soil effects that enter into seismic microzonation, engineering interest focuses on assessing (1) soil liquefaction potential, (2) soil densification characteristics, (3) loss of soil strength due to dynamic loading, and (4) shear moduli and damping properties of soils. The first three soil factors provide information on the strength and stability of the soil deposits in the area, while the fourth is used in analytical estimation of ground response, from which the magnitudes of accelerations, and hence the forces to which the structures in the area will be subjected during earthquakes are determined.

● **5.2-12** Arya, A. S. *et al*, **Verification of liquefaction potential by field blast tests,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 865–872.

Data obtained from a shaking table test of the liquefaction potential of a cohesionless soil showed that the simplified procedure of Seed and Idriss gives highly conservative results. It was therefore felt desirable to verify the conclusions by blast tests at a site. A method was developed to compute the anticipated pore pressure rise indicated by the design earthquake. During the equivalent motions generated in the field, the rise in pore pressure was measured and compared with computed rises. It was observed that even the shaking table test data were conservative.

● **5.2-13** Troitsky, A. P., **The influence of non-linear material strain due to seismic impact upon vibration behaviour of earth-fill dams,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-50, 1978, 373–377.

Based on the nonlinear shear modulus-deformation relationship for natural noncohesive soils, the results of one-dimensional nonlinear elastic shear vibrations of an earthfill dam of trapezoidal cross section are presented. It is shown that the nonlinear properties of the structural material substantially influence the dynamic structural behavior.

● **5.2-14** Sugimura, Y., **Seismic shear strain induced in soil deposits,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 933–944.

A method for estimating seismic ground strain by use of the elastic wave propagation technique for strong-motion data and results computed with this technique are presented. One hundred and fourteen components of strong-motion data, recorded at 15 sites in California where soil conditions are known, are used as analytical examples to determine the seismic shear strains in the ground. According to these results, the following can be concluded: (1) There exist a set of directions–the predominant and the lowest components are perpendicular to each other, and the parallel and normal directions of the causative fault line correspond to such a coordinate system. (2) There is some correlation between the maximum velocity response at the ground surface and the maximum shear strain in the soil deposits.

● **5.2-15** Iwasaki, T. *et al.,* **A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 885–896.

A simplified method for assessing liquefaction potential of sandy deposits is proposed. The ability of a soil 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 the ground. A procedure is proposed for estimating R from standard penetration N-values, effective overburden pressure and mean diameter. L is estimated from the expected maximum horizontal acceleration at the ground surface, a reduction factor to account for ground deformation, the soil density, and the water table. The method was applied to sites where liquefaction had occurred and where appropriate geotechnical information was available. It was found

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that the method is adequate for assessing liquefaction potential.

● **5.2-16** Dezfulian, H. and Prager, S. R., **Use of penetration data for evaluation of liquefaction potential,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 873–884.

This paper presents results of a method using field data to evaluate the earthquake-induced liquefaction potential of granular soils. Data was obtained from standard penetration test results and static cone penetrometer soundings. Results from field and laboratory testing programs were used to identify the occurrence of granular layers and to determine the characteristics of each layer. An analysis was made of relative density and the correlation between N values from the borings and q_c from the penetrometer soundings, enabling the penetrometer data to be converted to corrected N-values.

The liquefaction potential was evaluated by determining the resisting soil stress ratio from behavior of other granular sites during earthquakes and dividing by the induced stress ratio from the design earthquake. A correlation between soil characteristics (determined by the standard penetration test) and liquefaction potential (using induced earthquake accelerations and observed site behavior) has been established by Seed and is used in this paper. A comparison is made between the factors of safety using the field data approach and the approach using induced stresses from acceleration time histories and strengths from laboratory cyclic triaxial testing.

● **5.2-17** Yoshimi, Y. and Tokimatsu, K., **Two-dimensional pore pressure changes in sand deposits during earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 853–863.

An analytical method applicable to two- and three-dimensional problems is presented for evaluating the generation and dissipation of pore water pressures in sands during earthquakes. The method is an extension of Biot's consolidation equation. Shaking table tests were conducted on a horizontal layer of saturated sand supporting a structure, and the test results were compared with the computed values based on the mechanical properties of the sand which were determined at appropriate stress levels in the model tests. The computed pore pressure time histories of the sand were in good agreement with the observed ones, considering that the pore pressures were sensitive to a small variation in the table acceleration. It was indicated that redistribution of pore pressures resulting from seepage should be taken into account when evaluating the bearing capacity of saturated sand subjected to cyclic loading.

● **5.2-18** Nemat-Nasser, S. and Shokooh, A., **A new approach for the analysis of liquefaction of sand in cyclic shearing,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 957–969.

When a sample of sand under fixed confining pressure is subjected to cyclic shearing, its grains are rearranged; and, as a consequence, the saturated undrained sample may liquefy. This paper presents a fundamental systematic approach for 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 analytical results are compared with existing experimental results and good correlations are obtained.

● **5.2-19** Singh, R. D., Gardner, W. S. and Dobry, R., **Post cyclic loading behavior of soft clays,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 945–956.

The load-deformation behavior of soft silty clay has been investigated with specific reference to the change in undrained static shear strength and stress-strain behavior induced by prior undrained cyclic loading. Both controlled-strain triaxial compression and direct simple shear tests were employed in the laboratory testing program as well as procedures to mitigate the effects of sample disturbance. Static loading to failure was conducted after cyclic loading and subsequent to a pore water pressure equalization period. Experimental results suggest that the effect of cyclic loading is to induce a partial remolding of soil structure which is represented by the amount of excess pore pressure existing after cyclic loading. Both stress-strain and shear strength characteristics were found to be affected by cyclic loading, the effect on the stress-strain relationship being the more significant. In general, the observed post-cyclic loading behavior was found to be consistent with the findings of Castro and Christian, Gardner, and Koutsoftas. The concept of describing the behavior of cyclically loaded overconsolidated clays suggested by Gardner and Koutsoftas is developed into a formal model and its validity is assessed. The model is an extension of the normalized soil parameter characterization method proposed by Ladd and Foott. It is proposed that the model be used to predict post-cyclic stress-strain behavior as well as undrained strength after either steady state or transient cyclic loading.

● 5.2-20 Capecchi, A., Conti, G. and Tafanelli, A., **Proposed methodologies for measurement of the characteristic longitudinal wave velocities in soil samples,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-04, 1978, 23–28.

Some laboratory methodologies for the measurement of longitudinal wave propagation velocity in soil samples are described. Each methodology is criticized based upon the findings and on possible applications.

● 5.2-21 Iwasaki, T., Tatsuoka, F. and Takagi, Y., **Shear moduli of sands under cyclic torsional shear loading,** *Soils and Foundations,* **18,** *1,* Mar. 1978, 39–56.

To evaluate the degree of reduction in the shear moduli of sands with an increase in shear strain amplitude, dynamic soil tests were performed using hollow cylindrical samples and the application of torsional shearing forces. Two types of soil testing equipment, a resonant-column apparatus and a torsional shear apparatus, were employed. It is pointed out that shear moduli at shear strain amplitudes of 10^{-4} obtained using these two types of equipment agree satisfactorily. The extent of shear moduli reduction with an increase in shear strain amplitude is shown for various sands. These data are compared with those presented by other investigators. On the basis of the test results, a simplified procedure for predicting the reduction in shear modulus with an increase in shear strain amplitude is proposed.

● 5.2-22 Ishihara, K. and Okada, S., **Yielding of overconsolidated sand and liquefaction model under cyclic stresses,** *Soils and Foundations,* **18,** *1,* Mar. 1978, 57–72.

Static undrained triaxial shear tests were performed on sand specimens overconsolidated to OCR-values of 1.0 to 5.0 under cyclic as well as monotonous loading conditions. It was discovered that pore water pressures and shear strains which developed during undrained shear tests were lower for overconsolidated sand than for normally consolidated sand, even when the density of the sand was kept virtually unchanged. To advance a reasonable interpretation for the hardening effect caused by overconsolidation, the concept of yield loci was introduced, establishing a family of curves in the stress space (effective mean principal stress versus deviator stress plot) which governs the onset of yielding in overconsolidated sand. On the basis of the yield loci established, the deformation model previously established for normally consolidated sand was modified and generalized so that the pore water pressures and shear strains under irregular loading conditions could be predicted for both normally and overconsolidated states.

● 5.2-23 Tokue, T., **A consideration about Rowe's minimum energy ratio principle and a new concept of shear mechanism,** *Soils and Foundations,* **18,** *1,* Mar. 1978, 1–10.

Rowe introduced a new concept called the minimum energy ratio principle to obtain a stress-dilatancy relation of granular materials under axisymmetric stress conditions. According to the principle, the sliding contacts are restricted to those with a preferred angle. However, the physical basis of this principle is questioned by many investigators. In this paper, the author investigates this principle only on the basis of equilibrium between interparticle forces. The results include (1) Horne's study of Rowe's stress-dilatancy equation is incomplete to clarify the physical meaning of the minimum energy ratio principle. Accordingly, Horne's indication that the principle could be rigorously established as an equilibrium condition is not acceptable. (2) Minimizing the incremental energy ratio in Rowe's theory is equivalent to maximizing a driving tangential force F_d acting in the same direction as a sliding direction and a resisting force F_r in the opposite direction of F_d. The physical basis is not clear.

A new and simple concept of shear mechanism of granular materials can be proposed only on the basis of equilibrium between interparticle forces without using the minimum energy ratio principle. The concept can be described as that of shifting as shear stress increases. The development of anisotropy in grain structure during shear and deformation behaviors under cyclic loading can be explained well with use of the concept.

● 5.2-24 Tatsuoka, F., Iwasaki, T. and Takagi, Y., **Hysteretic damping of sands under cyclic loading and its relation to shear modulus,** *Soils and Foundations,* **18,** *2,* June 1978, 25–40.

Comprehensive tests were performed to obtain hysteretic damping of normally consolidated reconstituted sands using a resonant-column apparatus and a static torsional shear device. It is shown that there is a simple relationship between the ratio of shear modulus to the shear modulus at very small strain levels and the damping ratio for sands tested. This relationship is not affected considerably by void ratio and confining pressure for shear strain amplitude from 10^{-6} to 10^{-2}.

● 5.2-25 Wasti, Y., **Determination of the maximum unit weight of cohesionless soils by vertical vibrations** (Dusey titresimlerle kohezyonsuz zeminlerin maksimum birim agirliginin tayini, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 5, *20,* Jan. 1978, 52–67.

Experimental results of the effects of displacement amplitude, sample height and diameter, and surcharge weight on the maximum unit weight of cohesionless soils as determined by compacting the soil in cylindrical containers on a vertically vibrating table are presented. Experimental

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procedures to bring about the highest value of unit weight, based on the relative importance of these factors, are suggested. The variation of density along the height of the vibrated sample is examined.

● **5.2-26** Ozkan, M. Y., Soydemir, C. and Gurpinar, A., **Correlation of earthquake ground motion and dynamic soil parameters** (Deprem hareketi ve dinamik zemin parametreleri iliskisi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 5, *17,* Apr. 1977, 1-20.

The determination of suitable dynamic soil parameters is an important problem in the dynamic response analysis of soil deposits under seismic excitation. In this study, the variation of dynamic soil parameters with the depth of soil layers under band-limited white noise base excitations is presented. It is concluded that the variation of shear modulus and damping ratio with depth do not differ significantly if the root-mean-square values of the band-limited white noise base excitations are the same, regardless of the time histories of the accelerations.

● **5.2-27** Finn, W. D. L. and Erguvanli, A., **Stress-deformation relations for dynamic soil behavior** (Zeminlerin dinamik davranislarina ait gerilme-deformasyon bagintilari, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **5**, *17,* Apr. 1977, 40-52.

This paper examines the factors affecting the modulus variation of cohesive soils during and after cyclic loading and points out that these factors should be taken into consideration when calculating nonlinear response in the time domain. The dynamic behavior of cohesive soils is characterized by their shear modulus, and the response of soil layers is partly determined by their moduli. Up-to-date research has shown that the shear modulus of clays is dependent upon such external factors as the applied shearing strain amplitude and the number of repetitions of the strain. These effects are associated with an increase in pore water pressures during cyclic loading, strain accumulation, and deterioration of the clay fabric, especially in soft clays.

One of the governing factors for determining the soil response is the stress-strain relationship of the soils during and after cyclic or random loading. The nonlinear relationship between the shear modulus and applied strain has been demonstrated by many investigators. It is apparent that cyclic strains cause a progressive decrease in the modulus as well as a strain accumulation. This becomes more significant at high strain levels, and very little effect should be anticipated at strain amplitudes of less than 0.01%. The nonlinear decrease of the shear modulus with increasing strain has been modeled as various stress-strain relationships, including (1) the hyperbolic stress-strain relationship as defined by Hardin and Drnevich; (2) the relationship defined by the Ramberg-Osgood equation; and (3) the Seed-Idriss empirical relationship between shear modulus and strain.

A comparison of results for cohesive soils obtained by these relationships is given in this paper. The decrease in static modulus after cyclic loading as a function of the cyclic strain ratio is also given.

● **5.2-28** Prevost, J. H., **Plasticity theory for soil stress-strain behavior,** *Journal of the Engineering Mechanics Division, ASCE,* **104**, *EM5,* Proc. Paper 14069, Oct. 1978, 1177-1194.

A general analytical model that describes both drained and undrained, anisotropic, elastoplastic, path-dependent stress-strain-strength properties of inviscid saturated soils is presented. For any loading (or unloading) history, the instantaneous configuration of the field of yield surfaces is determined by calculating the translation and contraction (or expansion) of each yield surface during successive changes in load. The material behavior can thus be determined for complex, and, in particular, for cyclic loading paths. The inverse stress-strain relations always exist and are uniquely defined if and only if the yield surfaces do not overlap. In order to avoid such overlappings, a new isotropic/kinematic hardening rule is introduced which couples the simultaneous translation of consecutive surfaces. The isotropic/kinematic hardening of the outer surfaces is thus made compatible with any isotropic/kinematic hardening rule assumed for the inner surfaces.

● **5.2-29** Finn, W. D. L. and Yong, R. N., **Seismic response of frozen ground,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT10,* Proc. Paper 14106, Oct. 1978, 1225-1241.

Field data on the behavior of frozen ground during the Alaska earthquake of 1964 are reviewed. It is shown that fully frozen ground behaves well during earthquakes and that most engineering problems with frozen ground are encountered when saturated cohesionless soils are trapped beneath the frozen surface layer. A procedure for the dynamic effective stress response analysis of this situation is presented. Existing data on the stress-strain properties of frozen ground are reviewed critically. Use of seismic refraction techniques in frozen ground, both onshore and offshore, is considered. Freezing phenomena essential for understanding experimental data and field conditions are described.

● **5.2-30** Vinson, T. S., **Parameter effects on dynamic properties of frozen soils,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT10,* Proc. Paper 14109, Oct. 1978, 1289-1306.

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The results from previous investigations of frozen soils indicate: (1) Dynamic stress-strain properties for coarse-grained soils can be nearly an order of magnitude greater than for fine-grained soils, and energy-absorbing properties can vary significantly with soil type and composition; (2) over a range of void ratios from 0.3 to infinity (ice), dynamic stress-strain properties for fully saturated soils can decrease by a factor of 5; (3) dynamic stress-strain properties of frozen soils increase with increasing degree of ice saturation; (4) dynamic stress-strain properties decrease and damping properties increase with ascending temperature; (5) dynamic stress-strain properties decrease and damping properties increase with increasing axial strain amplitude from 10^{-3}% to 10^{-1}%; (6) the frequency of loading has only a minor effect on dynamic stress-strain properties, and the effect on damping properties may be important at low frequencies; and (7) confining pressure has an important effect on the dynamic properties of coarse-grained soils and a relatively unimportant effect on fine-grained soils.

● **5.2-31** Finn, W. D. L., Yong, R. N. and Lee, K. W., **Liquefaction of thawed layers in frozen soils,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT10,* Proc. Paper 14107, Oct. 1978, 1243–1255.

A dynamic effective stress method is presented for assessing the liquefaction potential of thawed layers of saturated cohesionless soils sealed between frozen surface layers and permafrost. Such layers are common in Arctic regions. Analysis indicates that the liquefaction potential is increased by the presence of a frozen surface layer. The pore-water pressures created by dynamic stress gradients are redistributed upwards to regions of lesser effective stresses. The pressures cannot dissipate because drainage is sealed off, thus causing increased liquefaction potential. Within limits yet to be established, the coarser the soil, the greater the risk of liquefaction will be at low densities, since upward redistribution of pore-water pressures is facilitated by increased permeability. Field data on liquefaction from the Alaska earthquake of 1964 are examined, and they appear to support the conclusions.

● **5.2-32** Idriss, I. M., Dobry, R. and Singh, R. D., **Nonlinear behavior of soft clays during cyclic loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT12,* Proc. Paper 14265, Dec. 1978, 1427–1447.

A new stress-strain model that accounts for the nonlinear and degradation characteristics of soft clays as a result of cyclic loading is developed based on the results of cyclic tests on specimens of San Francisco Bay mud. The model parameters were obtained from controlled-strain tests and the model was extended for an arbitrary cyclic loading history, such as that occurring during earthquakes, and was used to predict stress-strain response of controlled-stress tests. The main features of the proposed model include: (1) during every cycle, the stress-strain behavior of the soil is defined by a backbone curve and by the Masing criterion; (2) the backbone curve is represented by the Ramberg-Osgood formulation; (3) the ordinates of the backbone curve decrease (degrade) during cyclic loading by an amount measured by a degradation index that represents an irreversible degradation process in the structure of the soil; and (4) the rate of degradation is controlled essentially by the amplitude of the cyclic strain.

● **5.2-33** Tatsuoka, F. and Fukushima, S., **Stress-strain relation of sand for irregular cyclic excitation (I)** (in Japanese), *Seisan-Kenkyu,* **30,** *9,* 1978, 26–29.

● **5.2-34** Tatsuoka, F. and Fukushima, S., **Stress-strain relation of sand for irregular cyclic excitation (II)** (in Japanese), *Seisan-Kenkyu,* **30,** *10,* 1978, 9-12.

5.2-35 Fischer, K. P., Andersen, K. H. and Moum, J., **Properties of an artificially cemented clay,** *Canadian Geotechnical Journal,* **15,** *3,* Aug. 1978, 322–331.

A high clay strength and apparent preconsolidation may result from chemical processes such as cementation at the contact points of the clay particles. In order to study some of the mechanical properties of a cemented clay, two artificially cemented simple shear samples were produced and tested. Their engineering properties were compared to those of non-cemented clay samples with a real preloading. The cementing agent that was introduced into the sample was $CaCO_3$. This was achieved by a sequence of treatments of $CaCl_2$, Na_2CO_3, and original pore water. The different solutions were transported into the samples by diffusion. The cementation process took 90 days. The average amount of $CaCO_3$ introduced into the two samples was 3.3 and 4.2%, respectively. By electron microscope techniques, it was revealed that calcium carbonate was precipitated in spots of 5-10μm diameter. One of the samples was run with undrained static loading, and the other sample was first subjected to undrained cyclic loading and then to undrained static loading. Cementation increased the horizontal shear stress at failure by 35-40%. This corresponds to an apparent overconsolidation ratio of about 1.75. For both static and cyclic loading, the engineering properties were essentially independent of whether their high strength was achieved by cementation or by a real preloading.

● **5.2-36** Mroz, Z., Norris, V. A. and Zienkiewicz, O. C., **An anisotropic hardening model for soils and its application to cyclic loading,** *International Journal for Numerical and Analytical Methods in Geomechanics,* **2,** *3,* July–Sept. 1978, 203–221.

An anisotropic hardening model for soils is formulated by applying the concept of a field of hardening moduli developed previously for metals. Besides the yield surface, a set of nesting surfaces in the stress-space specifies the variation of hardening moduli during the deformation

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process. Both drained and undrained soil behavior can be treated, and distortional as well as volumetric strain cycles can be considered. The model can be applied to study soil behavior under cyclic loading and, in particular, to describe densification or liquefaction phenomena.

● 5.2-37 Van Eekelen, H. A. M. and Potts, D. M., **The behaviour of Drammen clay under cyclic loading,** *Géotechnique,* 28, 2, June 1978, 173–196.

A model for the behavior of clay under static and cyclic loading is developed based on test results for Drammen clay. The static part of the model is an adapted version of modified cam clay. The effects of cyclic loading are described in terms of a single fatigue parameter, namely, the pore-water pressure generated by cyclic loading. The cyclic part of the model comprises three basic formulas and contains only four parameters. It has been formulated throughout in terms of effective stress and strain invariants and can be applied to arbitrary loading histories for clay elements with arbitrary initial states or consolidation histories.

● 5.2-38 Ichihara, M. *et al.*, **Measurement of earth pressure during earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 102, Nov. 1978, 809–816.

The authors developed a large-scale vibrating soil bin with a movable wall for the measurement of passive earth pressure during an earthquake. This soil bin can be vibrated with a frequency of 2.7 Hz and a maximum acceleration of 500 gals. The movable wall is separated into two symmetrical parts. Since each part of the wall is adjusted with its counterweight, the readings of load cells do not include any influence for the inertia force of the wall.

In this experimental study, dense Toyoura sand was used and the wall was translated horizontally. Properties of the passive earth pressure during oscillation were studied. The three elements of earth pressure, i.e., the normal component of the resultant earth pressure, the height at the applied point of the resultant pressure, and the coefficient of wall friction, are obtained and the coefficient of earth pressure is given. The relationship between the three elements of the earth pressure and the displacement of the wall is shown. The coefficient of earth pressure shows the maximum value before the full mobilization of the coefficient of wall friction. The displacement of the wall at maximum earth pressure was 10 mm; the angle of wall friction was about 20.5 degrees. As the acceleration became larger, the passive earth pressure gradually decreased at the maximum inertia force, i.e., at the time when the force traveled from the wall to the backfill sand and when the magnitude of the force became maximum. Comparing the values of the measured earth pressure with values calculated based on Mononobe's equation and on the logarithmic spiral method, it is found that the measured values are much greater than the calculated values. In order to fit Mononobe's equation using the measured angle of wall friction to the measured earth pressure, it is necessary to assume an angle of internal friction of 46 or 47 degrees. Considering cohesion of the sand, the calculated values of the earth pressure during earthquakes based on the logarithmic spiral method agree well with the measured ones.

● 5.2-39 Tokimatsu, K. and Yoshimi, Y., **Generation and dissipation of pore water pressures in sand during earthquakes** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 77, Nov. 1978, 609–616.

This paper studies the generation and dissipation of pore water pressure during earthquakes in sand deposits involving two- and three-dimensional configurations and seepage paths. The object is to establish rational criteria for soil stabilization during earthquakes. An analytical method, which is an extension of Biot's consolidation equation, is outlined. The method takes into account the distribution of dynamic shear stress as well as static shear stress on the horizontal plane in the sand and the probable influence of pore water pressure redistribution. Shaking table tests were conducted on a model structure placed on saturated sand with and without gravel drains. The gravel used for the drains was about 250 times more permeable than the sand. The test results were compared with the analytical results based on the mechanical properties of sand determined at the appropriate stress level in the model tests. This procedure was expected to facilitate a straightforward verification of the analytical method without considering similitude requirements.

The computed pore water pressure time histories in sand were in fairly good agreement with the observed values. The model tests and the analysis show that (1) excess pore water pressure buildup in the sand directly below the structure is mainly due to seepage from the surrounding area which would liquefy more easily than below the structure; (2) the presence of the gravel drains around the structure has a considerable influence on reducing the pore pressure buildup below the structure and the settlement of the structure.

On the basis of the analytical and experimental studies presented in this paper, it may be concluded that the proposed procedure is applicable to predicting pore water pressure changes in saturated sand during earthquakes for two- and three-dimensional problems. The excess pore water pressures in saturated sand supporting a structure indicate that redistribution of pore water pressures due to seepage should be taken into account in evaluating the bearing capacity of the sand during earthquakes.

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● 5.2-40 Taga, N. and Togashi, Y., **Dynamic properties of saturated soil layer** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 99, Nov. 1978, 785–792.

A soil layer with a porous structure and pore water is assumed to be composed of solid material and fluid. The effect of the microstructure in the soil medium on the vibrational properties of the ground is presented and discussed using wave propagation theory and the finite element method. The ground consists of two layers on a base—one is a monophase layer with no microstructure and the other is a water-saturated soil layer idealized as a composite continuum. Free vibration, steady state and seismic response results are summarized.

Dynamic properties of the ground with a microstructure are characterized by the interaction effect between the soil skeleton and pore water, i.e., the relative motion of two kinds of particles and the permeability of a porous medium. The stiffness and damping ratio change depending upon the type of propagating waves when the soil layer is saturated with water. Shearing motion in the saturated layer softens the ground stiffness and adds damping effects to the soil layer, while dilatational motion increases ground stiffness and damping. The overall behavior of the composite ground indicates that the amplification factor and the fundamental frequency decrease in the shearing motion, while in the dilatational motion, the magnification ratio and damping factor increase because of the higher compressive stiffness of water. The increase in the saturated area of the soil layer emphasizes the effect of water saturation. The material stiffness of the soil skeleton affects the influence of pore water on the dynamic behavior of the soil layer; this is especially significant during dilatational wave propagation.

● 5.2-41 Sugimoto, M., Hatanaka, M. and Tatsumi, Y., **Dynamic properties of a soft marine clay and modelling its stess-strain behavior for dynamic response analysis** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 90, Nov. 1978, 713–720.

The object of this paper is to study the dynamic properties of soft marine clay and to determine an analytical model of the stress-strain behavior of the clay by means of the Ramberg-Osgood curve. These studies will aid in performing earthquake response analyses of soil-structure systems. A series of undrained cyclic triaxial compression tests were conducted on soft marine clay which was obtained by a thin-walled sampler at depths of 5 to 27 m below the bottom of Tokyo Bay. The natural water content of this clay is 110 to 120% with a plasticity index of 60 to 70. The unique feature of the test apparatus is that radial displacements during cyclic loading are measured at three different specimen heights by strain-gauge-type displacement gauges, so the dynamic shear modulus can be calculated from the shear stress and shear strain at each cycle without assuming Poisson ratios. Tests were conducted at a frequency of 0.5 Hz on all specimens, thus, dynamic properties at different levels of stress or strain could be obtained on the same specimen. These test results only for the 10th cyclic loading and with the strain level between 10^{-4} and 10^{-2} are used for modeling stress-strain behavior.

The following conclusions were obtained from the results of laboratory tests and analyses: (1) Test results showed that there was an approximately linear relationship between the equivalent shear modulus (Geq) and the equivalent hysteretic damping ratio (heq) irrespective of confining pressure and void ratio. (2) It was also shown that the linear relationship between Geq and heq could be derived from the analytical model of stress-strain behavior by using the Ramberg-Osgood curve. Fitting the test results into the above linear relationship, the maximum equivalent shear modulus (G_0) and the maximum hysteretic damping ratio (h_0) can be determined. (3) A method for the determination of three constants, G_0, R, and K of the Ramberg-Osgood curve, from the test results is presented, and it is found in this determination that the constant R is a unique function of the maximum damping ratio, h_0. (4) Test results of the strain-dependency of Geq and heq for soft marine clay can be estimated adequately by Ramberg-Osgood curves based on the above relationship between Geq and heq.

● 5.2-42 Taniguchi, E., Ogasawara, H. and Sawada, K., **Effects of shear strain on the dynamic deformation coefficients of clays**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 89, Nov. 1978, 705–712.

Dynamic shear moduli and damping ratios of soft clays were measured by using resonant column and cyclic triaxial compression apparatus. The shear modulus G (or damping ratio h) and shear strain γ relation was investigated on the basis of the test results and effects of confining pressure, time, and plasticity index on the G (or h) - γ relation were clarified. The conclusions obtained in the research are the following: (1) The value of G (or h) depends on shear strain even in the small strain region such as 10^{-6} - 10^{-4}. Shear modulus decreases and damping ratio increases with increasing shear strain. (2) The Seed-Idriss curve on the G - γ relation overestimates the decrease rate of G with γ and the Hardin-Drnevich curve underestimates it for the soil samples tested. (3) Confining pressure has substantial effects on the G (or h) - γ relation. The decrease rate of G with γ (or increase rate of h with γ) becomes larger if the confining pressure is smaller. (4) Time has almost no effects on the G - γ relation. (5) The relation between the decrease rate of G with γ and the plasticity index was not clearly determined from this series of experiments.

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● **5.2-43** Mizuhata, K., Fukusumi, T. and Ono, T., **In-situ tests for prediction of sandy ground liquefaction-by means of pile driving,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 80, Nov. 1978, 633-640.

A series of in-situ tests were carried out on sandy soil at two sites. The pile driving method was used in the tests. The purpose was to examine the use of in-situ tests for the prediction of liquefaction. The relationship between excess pore water pressure and acceleration at the same depth was studied. It is concluded that there is a linear relationship between dynamic pore water pressure and the magnitude of acceleration in the ground and that this information can be used in in-situ tests to compare the liquefaction potential of sandy soil layers.

● **5.2-44** Ohsaki, Y., Hara, A. and Kiyota, Y., **Stress-strain model of soils for seismic analysis** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 88, Nov. 1978, 697-704.

To accurately evaluate the effects of earthquake motions on soil deposits and structures founded thereon, it is necessary to establish a stress-strain model of soils that exactly represents experimental results both in the field and in the laboratory. As seen from a number of dynamic shearing test results of various soil samples, the dynamic characteristics of soils of primary importance are the dependencies of the soils upon strain, frequency, and number of cycles of applied stress. An equation for the stress-strain relationship is proposed, and the procedures to determine the parameters are described. When deriving hysteresis curves from the equation, if it is assumed that soils behave in a Masing-type manner, a reasonable relationship is determined between the shear modulus, the damping factor, and the shear strain. The equation can also be applied to the problem of random excitation within a soil mass during an earthquake. The results of analyses using the proposed equation show good agreement with laboratory and field results.

● **5.2-45** Iwasaki, T. *et al.*, **A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 81, Nov. 1978, 641-648.

A simplified analytical method for assessing soil liquefaction potential is developed. In this method, the ability of a soil deposit to resist liquefaction is represented by a 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 for estimating R by equations obtained from standard penetration N-values, effective overburden pressure, and mean diameter. L can be estimated by an equation obtained from data of the estimated maximum horizontal acceleration at the ground surface and from a reduction factor to account for deformation of the ground, soil density, and the water table. This method was applied to various sites where liquefaction had occurred in the past and where appropriate geotechnical information was available. It is found that this method is quite adequate for assessing liquefaction potential during earthquakes.

● **5.2-46** Yasuhara, K. and Hirao, K., **Strength and deformation of a saturated soft clay subjected to cyclic loadings,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 92, Nov. 1978, 729-736.

Dynamic and static triaxial tests on a saturated soft marine clay have been carried out under drained and undrained drainage conditions. The paper examines the large strain performance of a clay under impulsive-type loadings and presents some results of the seismic behavior of saturated clay. The results indicate that the ultimate dynamic strength at 15% shear strain in terms of the effective stress is not affected by the frequency of cyclic loadings and the drainage condition but that the ultimate strength becomes slightly lower than the static strength at the same loading conditions. A hyperbolic relationship between pore water pressure and shear strain is introduced. The relationship is independent of the loading method (dynamic or static). It appears that dynamic and static shear strains resulting from triaxial tests are approximately the same when the effects of creep are excluded. The dilatancy effect developed in cyclic drained tests is governed not only by the stress ratio but also by the frequency of cyclic loadings. This tendency, which is different from that of undrained cyclic triaxial tests, suggests that the hydrodynamic time lag plays an important part in deformation during drained cyclic loadings of saturated clay with low permeability.

● **5.2-47** Zen, K., Umehara, Y. and Hamada, K., **Laboratory tests and in-situ seismic survey on vibratory shear modulus of clayey soils with various plasticities,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 91, Nov. 1978, 721-728.

The effects of the plasticity index on the shear moduli of clayey soils are investigated using a resonant column device and a dynamic triaxial test apparatus. It is found that the plastic index affects the low amplitude shear modulus, stress-strain curve, and secondary increase in shear modulus. The laboratory test results are compared with the results obtained from an in-situ seismic survey.

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The differences between the experimental and theoretical results are analyzed and discussed.

● 5.2-48 Gyoten, Y., Fukusumi, T. and Sakaguchi, T., **Study on the dynamic properties of soil,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 87, Nov. 1978, 689–696.

In determining the response of ground during an earthquake, dynamic properties and behavior of the soil should be clarified. The shear modulus and damping properties of soils have been studied and a response analysis for soil and ground which takes into account nonlinear characteristics has been developed. In this study, alluvial and diluvial clay samples were tested by using a dynamic triaxial compression testing machine and the soil model applicable to the response analysis of ground is discussed. The experimental results indicate that the equivalent stiffness and the equivalent viscous damping factor are not affected by the mean stress that will vary during a random excitation load such as an earthquake. By considering the hysteresis curve which is dependent upon strain amplitude, the fourth-order algebraic function for expressing hysteresis curves is adopted. The responses of a soil layer subjected to sinusoidal excitation were examined using the proposed model of the soil.

● 5.2-49 Nishi, M. and Tanimoto, K., **A consideration in determining elastic properties of granular materials under laboratory dynamic loading,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 93, Nov. 1978, 737–744.

An analysis of the results of repeated load tests on densely compacted specimens of two granular materials suggests three aspects of their soil structure: (1) the occurrence of different initial soil structure, (2) the possibility of alterations in soil structure due to loading, and (3) the existence of a soil structure compatible with the applied stress conditions. The last two aspects are also evidenced by the results of subsequent damping torsion tests using the same dense specimen. Moreover, it is suggested that the resilient, or recoverable, properties determined under the compatible soil structure can be correlated with the stress conditions in a small scatter-band width.

● 5.2-50 Nakase, A., Nakanodo, H. and Kusakabe, O., **Influence of soil type on pore pressure response to cyclic loading,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 75, Nov. 1978, 593–600.

The paper reports the pore pressure response of soils subjected to static and dynamic loadings, with special reference to the change in soil type from sand to clay. Reversed cyclic loading tests were performed on the samples which were prepared by mixing a clay and crushed sand to obtain a wide range of soil type expressed in terms of a sand fraction or a plasticity index. Stress amplitude was 10 to 40% of the undrained static shear strength. In view of the strain rate requirement for pore pressure measurement in clay, the frequency was reduced to 0.003 Hz. It was found that the pore pressure buildup that occurred immediately after a number of cyclic loadings increased with the sand fraction and that this trend became marked as the sand fraction approached 60%. Results of the cyclic loading tests indicate that the stability of cohesive soils during earthquakes should be examined in view of the pore pressure buildup at the time of an earthquake. In order to demonstrate the effect of pore pressure buildup, numerical examples are presented. Pore pressure distributions in normally consolidated foundation soil beneath an embankment before and immediately after an earthquake are calculated and the factors of safety against shear failure are compared. These examples show the importance of considering pore pressure buildup in cohesive soils at the time of earthquakes, prior to the occurrence of liquefaction.

● 5.2-51 Imai, T. and Yokota, K., **The buildup process of pore-water pressure in sandy soil during cyclic shear test** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 76, Nov. 1978, 601–608.

A detailed study of the process of pore water pressure buildup is presented. Dynamic triaxial testing equipment was used to test soil samples. It was found that the normalized buildup process of pore water pressure varied considerably depending upon whether the sample was of disturbed or undisturbed sandy soil. Certain functions were assumed for the normalized relation, and these functions proved to be convenient for expressing the buildup process of excess pore water pressure. These functions are expressed by α (for a disturbed sample) and β (for an undisturbed sample). The appropriateness of these functions was also verified by test data obtained elsewhere. The values of α and β were obtained from all samples and the relationship of these values with soil properties and stress ratios was examined.

● 5.2-52 Krizek, R. J., Ansal, A. M. and Bazant, Z. P., **Constitutive equation for cyclic behavior of cohesive soils,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 557–568. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Endochronic theory is employed to develop a relatively general constitutive relationship to model the dynamic behavior of cohesive soils subjected to multidimensional stress or strain paths. The proposed constitutive law is capable of describing strain softening and hardening,

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densification and dilatancy, frictional aspects, and rate dependence of the stress-strain behavior. The proposed law also accounts for pore pressure response in undrained conditions by considering saturated soils as two-phase media. The theory is based on a series of new internal state variables that are defined in terms of semi-empirical intrinsic material relationships. The theory is able to handle elastic and inelastic strain histories for rate-dependent materials from the very beginning of their cyclic stress-strain path. The intrinsic relations involve ten material parameters, including the initial elastic modulus which must be determined from quasi-static and cyclic tests. Although limited data preclude the development at this time of specific correlations for the material parameters in terms of soil characteristics, this model offers improved interpretation and analysis of the cyclic behavior of cohesive soils. The mathematical model is applied to describe data from low-frequency cyclic constant-strain-rate tests on undisturbed samples and low-frequency cyclic constant-load-amplitude tests on slurry-consolidated samples of kaolin. Both tests are conducted under undrained triaxial conditions with pore pressure measurements. Emphasis is directed toward the behavior of cohesive soils under low-frequency, large-strain cyclic conditions, such as those associated with earthquakes.

● 5.2-53 Kuppusamy, T., **Block foundation subjected to coupled modes of vibration,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 429–436.

Two models are available in the literature to analyze footings subjected to dynamic loads. The models are the lumped parameter model and the elastic halfspace model. The analog model bridges these two models. The use of the analog model simplifies the dynamic footing problem to the analysis of a lumped parameter model. In practice, a footing under dynamic loads is subjected to coupled modes of vibration. The understanding of the behavior of footings will be greatly enhanced by analyzing footings subjected to coupled modes of vibration rather than independent modes of vibration. The general equations of motion of a footing subjected to a vertical force, horizontal force, and moment are derived. The parameters in the formulation are discussed from the standpoint of available literature. The parameters can be acquired from the analog model. The solutions are obtained by means of a digital computer. The effects of the various parameters of the soil and footing are studied and conclusions are derived.

● 5.2-54 Finn, W. D. L. *et al.*, **Cyclic pore pressures under anisotropic conditions,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 457–471. (For a full bibliographic citation, see Abstract No. 1.2–11.)

A significant factor in seismic stability studies of slopes and dams of noncohesive materials is the development of pore-water pressures under the complicated stress conditions acting on potential failure surfaces during an earthquake. The stress conditions are represented by consolidation under anisotropic stress conditions, static shear stresses on potential failure planes, and cyclic stresses representative of the earthquake loading. Using data from an extensive program of cyclic triaxial tests, it is possible to describe analytically with satisfactory accuracy the pore-water pressures resulting from cyclic loading as a function of the anisotropic consolidation stress ratio, the cyclic shear stress ratio, and the number of load cycles. The function describing the development of pore-water pressure greatly facilitates the computer analysis of the stability of slopes under cyclic loading.

● 5.2-55 Egan, J. A. and Sangrey, D. A., **Critical state model for cyclic load pore pressure,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 410–424. (For a full bibliographic citation, see Abstract No. 1.2–11.)

A theoretical model is developed to predict the magnitude of excess pore pressure that will develop from undrained cyclic and other repeated loading. The model is based on the concepts of critical state soil mechanics and is general with regard to type of soil, level of cycled stress, and boundary conditions of testing or in-situ stress state. Using the model, excess pore pressures can be predicted from measured values of fundamental soil properties, including volumetric compressibility and volume change potential. The model is tested and verified using data from 25 different soils. The soils range from uniform sands to highly plastic clays and represent a variety of in-situ and laboratory test methods.

● 5.2-56 Edil, T. B. and Luh, G.-F., **Dynamic modulus and damping relationships for sands,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 394–409. (For a full bibliographic citation, see Abstract No. 1.2–11.)

The dynamic response was obtained from resonant column tests of a large number of uniform-sized, dry sands and a limited number of sands with improved gradations. The data were analyzed to evaluate the effects of grain characteristics (size, gradation, shape, surface texture) and other test variables (e.g., ambient stress conditions, void ratio or relative density, strain amplitude, number of loading cycles) on the dynamic shear modulus and the damping capacity. The test results indicate that mean principal stress, density, and strain amplitude exert the strongest influence on both the modulus and damping capacity. Shear modulus is further influenced by roundness (used to characterize shape); the effects of the other parameters are either virtually zero or very small. Damping capacity is essentially independent of roundness and the other parameters, but it is influenced by the number of loading cycles. The test results are evaluated using multiple linear regression analysis, and empirical relationships correlating shear modulus and damping capacity to the important controlling parameters are obtained. The applicability of these relationships on other sands is assessed in a secondary testing program utilizing six different sand samples. These relationships and relationships proposed by other investigators are compared with the experimental data.

● 5.2-57 Bratton, J. L. and Higgins, C. J., **Measuring dynamic *in situ* geotechnical properties,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 272–289. (For a full bibliographic citation, see Abstract No. 1.2–11.)

A cylindrical dynamic in situ geotechnical material property test procedure is described. The test design and material property analysis are discussed. The analysis procedure involves iteration of the material properties for use in one-dimensional and two-dimensional finite difference models of the test until the data measured in the experiment are reproduced. Typical results for several different soil types are presented and comparisons are made with laboratory measured material properties.

● 5.2-58 Arulanandan, K. and Kutter, B., **A directional structure index related to sand liquefaction,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 213–230. (For a full bibliographic citation, see Abstract No. 1.2–11.)

A new index, the formation factor F, is proposed for characterizing the structure of sands. The formation factor F is obtained experimentally by expressing the ratio of the conductivity of the pore fluid and the conductivity of the sand solution system. Experiments performed on different sands show qualitatively the dependence of F on sand structure, especially on its elements associated with particle arrangement, particle shape, and porosity. F is also shown to be a valuable directional index parameter when the sand structure is anisotropic. This dependence, along with prospects for measuring F in-situ, provide a means to characterize the structure of sands in the field and to obtain empirical correlations among relative density, shape, and the anisotropic state of sand characterized in terms of F and the engineering behavior such as the liquefaction characteristics of sands.

● 5.2-59 Arango, I., Moriwaki, Y. and Brown, F., **In-situ and laboratory shear velocity and modulus,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 198–212. (For a full bibliographic citation, see Abstract No. 1.2–11.)

In this paper, field and laboratory shear wave velocity and shear modulus data are presented and compared. Field tests included down-hole and large-strain cross-hole geophysical methods while laboratory tests included resonant column and cyclic and static triaxial tests. The low-strain velocity values measured by two field testing methods (down-hole and cross-hole) were in reasonably good agreement, but the low-strain data from laboratory resonant column tests were approximately 50% lower than the corresponding field values. The modulus reduction data (G/G_{max}) from field cross-hole tests in general fell between the Seed-Idriss sand and clay reduction curves. Based on the data presented here and elsewhere, obtaining the maximum shear modulus based on shear strength should be used with caution, if at all. The low-strain ($<10^{-4}$ %) velocity in the field for most soils may be estimated approximately by multiplying the velocity value obtained from laboratory cyclic triaxial tests at 10^{-1} % strain by an empirically determined value of 2.3. The field shear wave velocity may be higher than the laboratory determined shear wave velocity by about 100% at low strain (10^{-4} %) and by about 25% at high strain (10^{-1} %). These differences were probably caused by disturbance and differences in boundary conditions. Finally, obtaining modulus reduction curves by combining field test data and laboratory test data may result in a significant error.

● 5.2-60 Anderson, D. G., Espana, C. and McLamore, V. L., **Estimating in situ shear moduli at competent sites,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 181–197. (For a full bibliographic citation, see Abstract No. 1.2–11.)

The use of laboratory testing methods and empirically derived equations for estimating the low-amplitude shear moduli of soils at four sites was examined. Shear moduli calculated from crosshole test data served as a basis for the comparisons. It was determined that, for sites where shear wave velocities exceeded 300 m/sec within depths of 10 m, empirical methods established by Hardin and Black, and Seed and Idriss typically underestimated in-situ moduli, whereas the method suggested by Ohsaki and Iwasaki overestimated moduli. Differences between measured and estimated shear moduli varied from 25 to 100%. Similar discrepancies were noted when laboratory moduli (resonant column) determined after one day of consolidation were compared to field moduli. Better agreement between field and laboratory moduli resulted when laboratory moduli were adjusted for long-term confinement effects.

● 5.2-61 Stoll, R. D., **Damping in saturated soil,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 960–975. (For a full bibliographic citation, see Abstract No. 1.2–11.)

A mathematical model is described which predicts damping and wave velocity in water-saturated soils. Two mechanisms for energy loss are included in the model; one accounts for inelasticity of the soil skeleton in a water environment and the other for viscous losses in the pore water as it moves in relation to the skeleton. As a result,

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damping which is frequency dependent occurs. The damping depends on such parameters as porosity, grain size, permeability, and effective stress.

The model is an extension of Maurice Biot's work and it has been used successfully to predict attenuation of acoustic waves in ocean sediments over a wide range of frequencies. It predicts that losses in the soil skeleton dominate at low frequencies, while viscous losses because of motion of the interstitial water become predominant at higher frequencies. The terms high and low are relative, with their actual values depending on the physical properties of the particular soil being modeled. For example, in very fine impervious materials, losses attributable to the skeletal frame control over most of the frequency range of interest, while, in sands, the viscous losses become important over a significant portion of this range. As a result, there is a marked variation of damping with frequency, making it nearly impossible to extrapolate outside the range of experimental results without the help of a physical theory such as the one described.

Because of the importance of pore fluid motion, results of vibration tests, such as the resonant column test, must be carefully interpreted in order to yield results which can be used to predict attenuation in propagating waves. Since viscous losses affect both shearing and extensional motion, all tests are subject to their influence. Curves are presented showing the effect on damping of various parameters such as frequency and permeability. The input for generating the curves is based on well-established data from the literature, and the results suggest an explanation for some of the early findings about saturated soils that were published but never fully interpreted.

● 5.2-62 Srinivasulu, P. *et al.*, **Vibration studies on jolter foundations,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 907-918. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Vibration commonly occurs in an industrial plant. Studies on the dynamic response of foundation-soil systems have received special attention in the recent past. The attention, however, has been largely confined to studies of the response of foundations experiencing steady-state dynamic loads. Relatively little information has been published on the design and performance of impulsively loaded foundations. This paper discusses a study of existing jolter foundations in an industrial plant. A jolter is essentially an impact-causing machine. Because of the limitations of the methods for designing these foundations and the scarcity of data required to make a rational analysis, the authors believe that case study data from existing foundations provides valuable information for evaluating their true behavior. The paper includes an explanation of the problem and the mathematical model used for computation. It also includes vibration measurements conducted at a site. It is shown that the "equivalent hammer analogy" is not applicable to foundations of machinery having a long duration of impact.

● 5.2-63 Srinivasulu, P. *et al.*, **Dynamic response of block foundations,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 890-906. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Modal analysis of block-type foundations, including damping, and data from vibration tests on surface and embedded footings are presented. It is found that unique values of damping ratio and spring constants cannot be used to predict the complete response of the foundations, although the resonant frequencies and resonant amplitudes can be reasonably estimated. Under the coupled horizontal and rocking mode, it is established that the minimum value of the damping constant occurs at resonance. An empirical relationship for predicting the damping at any particular frequency level is derived. The effects of surface roughness, embedment, backfill, etc., are briefly discussed. A simple mathematical model is presented to predict the response of coupled oscillations in block foundations.

● 5.2-64 Shen, C. K., Herrmann, L. R. and Sadigh, K., **Analysis of cyclic simple shear test data,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 864-874. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Cyclic simple shear test data obtained from the Norwegian Geotechnical Inst. (NGI) apparatus were examined and interpreted to better relate the data to actual soil behavior. The study was made using a linear elastic finite element analysis. Available data for a medium dense sand, a soft clay, and a chemically stabilized fine sand were analyzed. It has been shown that, for dynamic response determination, the NGI simple shear device may introduce an error ranging from 5 to 15% in shear modulus measurements.

● 5.2-65 Townsend, F. C., Marcuson, III, W. F. and Mulilis, J. P., **Cyclic triaxial and SPT for predicting liquefaction,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 976-990. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Liquefaction potential of sand deposits recently has been evaluated by Seed using converted standard penetration test (SPT) N values, based upon the concept that factors tending to improve liquefaction resistance also improve SPT resistance. The procedure compares SPT N values corrected to an overburden pressure of 1 TSF with stress ratios in the field. The objective of this research was to evaluate the correction factor, C_N, used to correct N values to an overburden pressure of 1 TSF for four different sands. Cyclic triaxial tests were also performed on these

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same sands. Using these laboratory data, extension of the data base from field observations was attempted.

● **5.2-66** Sangrey, D. A. *et al.*, **Cyclic loading of sands, silts and clays,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 836–851. (For a full bibliographic citation, see Abstract No. 1.2-11.)

This paper illustrates that the response of saturated soils (sands, silts, and clays) to cyclic loading may be described with one behavioral model. The behavioral model is based on critical void ratio and critical state concepts, i.e., the use of void ratio and effective stresses as key parameters in defining the state of the soil and, therefore, its response to cyclic loading.

Using the model for response of soils to cyclic loading, it is possible to understand: (1) strength reduction in sands (i.e., liquefaction) and in fine-grained soils in the contractive state; (2) levels of cycled stress which can be continued without significant strain; (3) maximum levels of pore water pressure developed under cyclic loading of contractive sands, silts, and clays; (4) the absence of strength reduction resulting from cyclic loading of undrained dilative soils, and (5) volume changes during and subsequent to cyclic loading. Test results from a variety of natural sands, silts, and clays are used to illustrate the behavioral model.

● **5.2-67** Saada, A. S., Bianchini, G. F. and Shook, L. P., **The dynamic response of anisotropic clay,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 777–801. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The process of sedimentation followed by one-dimensional consolidation results is examined for natural clays having cross anistropic mechanical properties with the axis of symmetry along the direction of consolidation. The results of the experimental investigation described in this paper demonstrate the importance of the clay fabric and the influence it has on the dynamic behavior. At high-frequency loadings, it is shown that substantial differences exist among the moduli obtained from vertical and horizontal specimens. At low-frequency cyclic loading, it is shown that the responses of the isotropic and anisotropic materials are totally different. An anisotropic clay does not turn into an isotropic clay, even under the most severe cyclic strains. Axial compression and extension tests cannot be substituted for simple shear tests in evaluating the dynamic properties of an anisotropic clay.

● **5.2-68** Prager, S. R. and Lee, K. L., **Post-cyclic strength of marine limestone soils,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 732–745. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A testing program was designed to evaluate the static shear strength of cohesive marine limestone soils following cyclic loads. The residual static strengths were compared to the conventional static strength envelope to determine the loss of strength resulting from cyclic effects. Residual strengths were also compared to the induced earthquake stresses to indicate the capacity of the soils to resist the earthquake loading.

● **5.2-69** Yong, R. N. and Ling, H.-P., **Finite element analysis of stress propagation in a clay,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 1097–1110. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The dynamic properties of elasticity and viscosity moduli of a clay soil under a one-dimensional transient compressive pulse are evaluated by the finite element method with frequency effects taken into account. These properties, expressed as functions of frequency, are used for subsequent analyses of stress propagation, using the normal mode method. One example problem is illustrated, and the response is compared with the experimental result. It is also compared with results derived when frequency dependency is not considered.

● **5.2-70** Prevost, J. H. and Hughes, T. J. R., **Mathematical modeling of cyclic soil behavior,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 746–761. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The analytical model proposed in this paper describes the anisotropic, elastoplastic, path-dependent stress-strain-strength properties of inviscid saturated soils subjected to complicated and, in particular, to cyclic loading paths. The formulation is general and incorporates both drained and undrained loading conditions. The extreme versatility and accuracy of the model are demonstrated by applying it to represent the undrained behavior of a particular clay under both monotonic and cyclic loading conditions. The model then is used in a finite element formulation to analyze the interaction of an offshore gravity structure with its soil foundation when subjected to cyclic wave loading.

● **5.2-71** Finn, W. D. L., Martin, G. R. and Lee, M. K. W., **Application of effective stress methods for offshore seismic design in cohesionless seafloor soils,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3112, 1978, 521–528.

The buildup of pore water pressures in saturated cohesionless soils during earthquake loading is of major significance in offshore design problems. Progressive increases in pore water pressure can lead to significant degradation of soil stiffness and potential liquefaction.

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Degradation of soil stiffness can have a major effect on soil-pile-structure interaction analyses, while liquefaction can lead to foundation stability problems and slope failures.

The recent development of basic equations relating shear stress, shear strains, and pore water pressure in saturated cohesionless soils during cyclic loading has enabled progressive increases in pore water pressure to be coupled with seismic response analyses of soil deposits resulting in a dynamic effective stress method of analysis. Because the physical behavior of sands is a function of effective stress, this development provides the means for more accurate computations of stiffness degradation and liquefaction potential. Emphasis is placed on potential applications of the effective stress methodology to soil-pile-structure interaction problems during earthquakes, where degradation effects influence the magnitude of soil coupling elements and free field input motions. The nature of the current API cyclic p-y curves for sands is discussed, and difficulties in applying these curves to earthquake analyses are outlined. The principles of the effective stress methodology are briefly outlined and its advantages over commonly used total stress methods are discussed. The practical applications of the effective stress approach are illustrated with reference to the free field response of a seafloor soil profile to earthquake ground shaking, the analysis of liquefaction, and the degradation of soil stiffness. The significant influence of factors such as the permeability and confinement of sand layers on earthquake response and stability calculations is demonstrated.

● 5.2-72 Finn, W. D. L., Lee, K. W. and Martin, G. R., **Dynamic effective stress analysis of sands,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/10, 1977, 231-236.

The proposed effective stress method can be used for the nonlinear analysis of saturated sands in which the dynamic properties are modified continually for the effects of dynamic shear strains, progressive increases in pore-water pressures, and strain-hardening. The method permits the computation of the distribution of accelerations, the shear stresses, and the shear strains in a saturated sand layer during an earthquake, the development of pore-water pressure distributions with time, and the liquefaction time.

● 5.2-73 Imai, T., **P- and S-wave velocities of the ground in Japan,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/15, 1977, 257-260.

An in-situ technique has been developed for measuring P- and S-wave velocities and used to accumulate velocity data. Particular attention has been given to the soft soil of the urban areas of Japan. The technique is called the PS logging system.

● 5.2-74 Sherif, M. A., Ishibashi, I. and Ling, S. C., **Dynamic properties of a marine sediment,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/39, 1977, 387-391.

Undrained, strain-controlled dynamic tests were performed with a torsional simple shear device on Pacific Ocean red clay. A loss of strength occurs with an increasing number of dynamic cycles, strain amplitudes, and frequencies. The equivalent shear moduli decrease while the damping remains almost constant with increasing cycles.

● 5.2-75 Sperling, G. and Hausner, H., **On the problem of the dynamic stability of soils,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/43, 1977, 405-408.

The paper deals with the parameters characteristic of the dynamic stability behavior of noncohesive sands subjected to stationary excitations by machine foundations. A wide range of analyses of machine footings resulted in empirical relationships between the dynamic soil parameters and the soil mechanics parameters. These analyses were carried out on dynamically loaded machine foundations resting on a ground of uniform fine, medium, and coarse sands.

● 5.2-76 Chou, I.-H. and Fischer, J. A., **Liquefaction and probability,** *Probabilistic Analysis and Design of Nuclear Power Plant Structures,* 39-50. (For a full bibliographic citation, see Abstract No. 1.2-17.)

The evaluation of liquefaction potential for a site ordinarily requires knowledge of the magnitudes and duration of seismic-induced stresses in the foundation soils and laboratory and/or in situ measurements of soil strength. Conventionally the liquefaction safety factor is expressed deterministically as the ratio of a single strength value to a single stress value. However, probabilistic concepts are applicable to an evaluation of soil strength parameters and the selection of the design earthquake. The paper describes a relatively simple approach for defining the liquefaction potential at a site by incorporation of the probabilistic nature of the earthquake hazard and the possible variations of soil strength measurements in any naturally occurring medium. An illustrative example is presented.

● 5.2-77 Taga, N., Ohtani, Y. and Ohhira, M., **Inelastodynamic properties of soil layers with various damping** effects (in Japanese), *Transactions of the Architectural Institute of Japan, 274,* Dec. 1978, 29–36.

A soil has various damping mechanisms, such as internal viscous damping, hysteretic damping because of material nonlinearity, and radiation damping from wave motion. The dynamic behavior of a soil layer subjected to strong earthquake motion is in a highly strained state under the above damping effects. To estimate the vibrational characteristics of highly strained soil layers exhibiting nonlinear behavior, a single ground layer on an elastic base is solved by the equivalent linearization technique using complex eigenvalue analysis. The surface motion and in-ground behavior are clarified by examining the transfer function of the layer, the strain distribution in the layer, and the corresponding strain-dependent rigidity reduction and hysteretic damping. The effect of the viscous damping, hysteretic properties, and base condition on the ground response is discussed. The importance of damping effects and material nonlinearity under strong earthquake motion is examined.

● 5.2-78 Taga, N. and Kimata, N., **Wave propagation properties of a multi-pile reinforced soil layer by continuum mixture theory** (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 69–80.

A soil layer reinforced with piles is assumed to be a composite of two solids. The fundamental dynamic properties and wave propagation characteristics of the complex ground composite are determined by applying two-phase medium mechanics. The theory is presented by averaging such physical quantities as displacement, stress, and density. The characteristic behavior of pile-reinforced ground as a two-solid medium is explained in terms of the difference of the relative displacements between two average solids. The dispersion resulting from the geometrical configuration of the pile ground is given and is shown to be mostly in the comparatively low-frequency range. The wave transfer properties are numerically analyzed and the coupling terms between two solid interfaces are discussed.

● 5.2-79 Kumbasar, V. and Erguvanli, A., **Effect of the plasticity index on shear wave velocity** (Plastisite indisinin kayma dalgasi hizina etkisi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **6**, *21,* Apr. 1978, 28–33.

Resonant-column tests were performed, at zero confining pressure and under small strain amplitudes, to study the effect of the plasticity index of different clayey soils on the shear wave velocity. The soils were compared at the same relative plasticity indices and the mineralogical compositions of the soils were determined qualitatively by DTA and X-ray diffraction analysis. The test results show a general tendency for the shear wave velocity to decrease with the increasing plasticity index of different soils at the same consistency.

● 5.2-80 Tatsuoka, F. *et al.*, **A method for estimating undrained cyclic strength of sandy soils using standard penetration resistances,** *Soils and Foundations,* **18**, *3,* Sept. 1978, 43–58.

Available data of sand sampling, dynamic triaxial tests on undisturbed specimens, *N*-values by standard penetration tests and gradings were analyzed and a correlation among dynamic shear strength was obtained. This correlation is represented by a simplified equation. Using this equation, approximate dynamic shear strengths of reclaimed and alluvial sandy deposits can easily be estimated.

5.3 Dynamic Behavior of Soils and Rocks

● 5.3-1 Ghaboussi, J. and Dikmen, S. U., **Liquefaction analysis of horizontally layered sands,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT3,* Proc. Paper 13601, Mar. 1978, 341–356.

A method is presented for the analysis of seismic response and liquefaction of horizontally layered saturated soils that are modeled as fluid-saturated porous solids. Coupled dynamic equations of motion are used, and nonlinear material properties are assigned to the solid granular portion. The paper describes the theory and the material model used. The proposed method is used in case studies, including a Niigata-like soil profile, and the results of the analyses are considered.

● 5.3-2 Tanimoto, K., Nishi, M. and Noda, T., **A study of shear deformation process of sandy soils by the observation of acoustic emission response,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 971–982.

Acoustic emissions in triaxial soil samples are observed to determine the shear failure processes of the soils. Acoustic emission is supposedly generated from interparticle friction during shear, and the patterns of acoustic emission may be connected with the growth of shear strain or time to failure. Acoustic emission also may be related to energy dissipated by friction during shear. This paper studies the relationships using data from two series of tests: strain-controlled and stress-controlled, under various confining stresses and soil conditions. The following results have been obtained: (1) The correlation between the time to failure and the emission rate, defined by the patterns of emission, is linear on a log-log scale as seen in a previous paper. Recent data for different soils substantiate this linear correlation. (2) An accumulated emission count monitored during a specified period of time is proportional to energy accumulated as a result of external stresses during the same period and used instead of energy dissipated by friction.

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

● **5.3-3** Ansal, A. M., Krizek, R. J. and Bazant, Z. P., **Endochronic constitutive law for soils,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-02, 1978, 9–14.

A new theory is proposed to model the behavior of soils under quasi-static and cyclic loads. The approach is based on the postulate that there exists a series of internal state variables and intrinsic material functions that on a macroscopic level represent the microstructural changes that take place in the soil during load application and how these changes accumulate along a stress or strain path. The proposed model has the advantages of accounting for (1) strain softening and hardening, (2) densification and dilatancy, (3) rate dependence, and (4) pore pressures in undrained conditions. The capabilities of the approach are demonstrated by fitting experimental data for both cohesive and cohesionless soils. A one-dimensional finite difference scheme is developed to model the shear wave propagation and to determine the susceptibility of soil to liquefaction.

● **5.3-4** Valanis, K. C. and Read, H. E., **A theory of plasticity for hysteretic materials-I: shear response,** *Computers & Structures,* 8, *3/4,* May 1978, 503–510.

A new endochronic theory of plasticity is presented which can predict accurately the mechanical response of hysteretic materials to complex shear straining histories, including cyclic deformation. The theory is based on a new definition of the intrinsic time measure recently introduced into the endochronic framework, which broadens its predictive scope. The present theory is motivated by considering a one-dimensional parallel assembly of basic endochronic elements, each of which consists of a linear elastic spring attached in series to a nonlinear endochronic slider. The extension of the concept to general three-dimensional states is straightforward and is discussed in this paper. Various unique features of the model are described, and the application of the model to the cyclic response of dry sand is illustrated.

● **5.3-5** Matsuoka, O. and Yahata, K., **The solution subjected to the harmonic point force in the interior of a semi-infinite elastic medium** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 54, Nov. 1978, 425–432.

This paper presents a solution for a semi-infinite elastic medium subjected to a harmonic point force in the medium interior. A new displacement potential is derived from the governing equations of the three-dimensional, homogeneous, isotropic elastic medium. Two types of harmonic forces, normal and tangential, are applied to the boundary of the medium. Vertical and horizontal displacements are calculated and discussed.

● **5.3-6** Yoshihara, S. and Takeuji, A., **Fundamental experiments on the liquefaction of the submarine sandy soil,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 78, Nov. 1978, 617–624.

This paper examines the liquefaction of submarine sandy soil during earthquakes. Shaking table tests were conducted of synthetic submarine soil. The excess pore water pressure generated in the synthetic sand was measured with differential pressure transducers. An analysis of the experimental results verifies that the excess pore water pressure generated in the soil was not related to the hydrostatic pressure caused by the sea water and that the pore water characteristics of the soil were very similar to those characteristics generated in saturated sandy soil on land.

● **5.3-7** Goto, H., Oka, F. and Kawamoto, K., **Liquefaction of soil and dynamic response of ground,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 85, Nov. 1978, 673–680.

The dynamic response of a soil layer considering liquefaction is analyzed numerically by a proposed simple method. A partial differential equation which is parabolic and hyperbolic governs the water flow and ground vibration during earthquake shaking. The finite difference method is used to approximate the governing equations. It is noted that the permeability of the soil layer and the occurrence of liquefaction have a substantial effect on the dynamic response of soil layers.

● **5.3-8** Finn, W. D. L., Martin, G. R. and Lee, M. K. W., **Comparison of dynamic analyses for saturated sands,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 472–491. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A number of methods are available for the analysis of the dynamic response of saturated noncohesive soils to earthquake loading. The methods differ in the simplifying assumptions that are made, in the representation of the stress-strain relations of soils, in the manner in which the development of pore-water pressure is taken into account, and in the methods used to integrate the equations of motion. Three methods, used in engineering practice, are applied to the same idealized site profile to compare the predictions, to assess the range of applicability, and to clarify the characteristics of each method.

● **5.3-9** Nishiyama, H. *et al.,* **Practical method of predicting sand liquefaction,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/24, 1977, 305–308.

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A simplified and practical method for predicting sand liquefaction is presented. The method consists of primary and secondary predictions. The primary prediction is performed with special attention to soil characteristics such as density and depth which can be obtained in a general soil survey. In the prediction, it is determined whether liquefaction might occur or whether a further response analysis might be required. For the secondary prediction, an analytical method is used. The simplified method proposed by Seed et al. is adopted with some modification as a result of comparisons with earthquake analysis of actual models having different geological and input wave conditions. The results are stated in terms of liquefaction, no liquefaction or the possibility of liquefaction. The above prediction procedures have been applied to actual examples of liquefaction with a high degree of accuracy.

● **5.3-10** Tinoco, F. H., **Pore pressure parameters and sand liquefaction,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/44, 1977, 409–418.

The undrained behavior of sand and clay samples is analyzed with a new set of pore-water pressure parameters that are independent of strain for pre-peak behavior of soil samples with a given initial structure and loading condition. Three types of undrained behavior of sands are defined as contractive, dilative, and contractive-dilative. The magnitude and sign of the new parameters are related to the type of behavior shown by the soil sample. The parameters are used to predict the number of cycles necessary to liquefy a sand sample in the laboratory. The parameters are also used, in conjunction with a dynamic analysis, to predict liquefaction in an element of the embankment of the Lower San Fernando Dam.

● **5.3-11** Taga, N. and Ohtani, Y., **Seismic response of nonlinear hysteretic soil layers** (in Japanese), *Transactions of the Architectural Institute of Japan, 271,* Sept. 1978, 53–60.

A realistic soil layer consists of a highly nonlinear medium with hysteretic characteristics. Such a soil medium exhibits strain-dependent rigidity and damping behavior. The strain level of a ground subjected to strong earthquake motion is on the order of 10^{-4} to 10^{-2}. Such a level must be used to estimate the nonlinear dynamic behavior (strain-dependent rigidity and hysteretic characteristics) of a soil layer subjected to a strong earthquake. By the step-by-step integration technique, the motion of a discrete lumped mass system for a soil layer is solved. The surface motion in terms of maximum displacement, acceleration, and the amplification factor in time domain is obtained. The response spectra and Fourier spectra of surface waves are also analyzed. The typical properties of the nonlinear dynamic response of the ground are discussed.

● **5.3-12** Zienkiewicz, O. C., Chang, C. T. and Hinton, E., **Non-linear seismic response and liquefaction,** *International Journal for Numerical and Analytical Methods in Geomechanics,* **2,** *4,* Oct.–Dec. 1978, 381–404.

The essential cause of an increase in pore pressure during cyclic loading is identified as an "autogenous" shrinkage or densification of the solid phase of the soil, and this is related to a strain path parameter. Introduction of this shrinkage coupled with an elastoplastic behavior of the soil skeleton allows a full nonlinear dynamic analysis to be conducted up to the point of structural failure for any earthquake input. Explicit time marching procedures are used. The procedure is applicable to all problems of complex geometry and for conditions of undrained or partially drained behavior with a moderate computational cost.

● **5.3-13** Martin, P. P. and Seed, H. B., **MASH - a computer program for the non-linear analysis of vertically propagating shear waves in horizontally layered deposits,** *UCB/EERC-78/23,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1978, 93. (NTIS Accession No. PB 293 101)

The computer program MASH is designed to analyze the dynamic response of a deposit of horizontal soil layers subjected to earthquake excitation. The deposit is discretized into a series of one-dimensional constant strain elements, and the equations of motion are integrated with respect to time by the cubic inertia method. The soil material may be either viscoelastic or nonlinear and may be modelled into the Davidenkov system of soil property expressions. The program may be used in conjunction with the program APOLLO to perform effective stress response analyses of soil deposits, in which pore pressures are generated and dissipated during and following the period of earthquake shaking. An example of this type of analysis, incorporating nonlinear soil behavior and pore pressure effects, is presented in the report.

● **5.3-14** Martin, P. P. and Seed, H. B., **APOLLO - a computer program for the analysis of pressure generation and dissipation in horizontal sand layers during cyclic or earthquake loading,** *UCB/EERC-78/21,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1978, 64. (NTIS Accession No. PB 292 835)

Several methods of expressing the rate of buildup of pore water pressures in a sand deposit subjected to earthquake shaking have been developed in recent years. They generally fall into one of two categories. (1) By referring to the fundamentals of the behavior of granular materials under cyclic shear stress applications, it has been possible to isolate the factors and the soil properties which determine the rate of pore water pressure generation. These data and mechanisms have been incorporated into methods of

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effective stress ground response analysis. Unless these basic soil characteristics can be measured with the required degree of accuracy, predicted pore pressures may be somewhat in error. (2) Use can be made of actual measurements of pore water pressure buildup in cyclic loading tests. The only criteria then required to evaluate pore pressure development in any soil element is the evaluation of the number of uniform stress cycles which will produce a condition of initial liquefaction under undrained conditions. This can readily be determined from undrained cyclic simple shear tests or other appropriate tests on representative samples.

A method of evaluating soil pore pressure generation and dissipation in horizontal sand deposits subjected to earthquake shaking using the principles described in (2) has been developed and shown to give reasonable results in comparison with the known behavior of the soil at Niigata, Japan, in the earthquake of 1964. This report describes the computer program APOLLO, in which the method has been incorporated, and gives a typical example of its application.

● 5.3-15 Sherif, M. A., Ishibashi, I. and Tsuchiya, C., **Pore-pressure prediction during earthquake loadings,** *Soils and Foundations,* **18,** *4,* Dec. 1978, 19–30.

The authors have previously proposed equations to predict pore-pressure rise under uniform and nonuniform dynamic shear stresses for a saturated Ottawa sand based on the results obtained from undrained cyclic shear experiments by means of the torsional simple shear device. In this paper, those previous studies are extended to earthquake-type loadings and to saturated Ottawa sands of different densities. Equations are proposed that predict the pore-pressure rise during earthquake loadings. The predicted and the measured pore pressures under shear stresses are compared, and a good correlation between the two is obtained. A diagram and a table are presented from which the four material parameters used in the above pore-pressure prediction equations can be readily obtained for any given void ratio or soil density.

● 5.3-16 Baligh, M. M. and Levadoux, J. N., **Consolidation theory for cyclic loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT4,* Proc. Paper 13708, Apr. 1978, 415–431.

This paper presents a one-dimensional consolidation theory for an inelastic normally consolidated clay layer subjected to cyclic loading. Analytical solutions predict the steady-state excess pore pressures and settlements that take place after a large number of cycles. Approximate solutions provide upper and lower bounds for the settlement history. Finite difference solutions agree with the theoretical analyses and provide useful predictions in case of rapid cyclic loading. Design charts and an example illustrate the use of the prediction method.

5.4 Dynamic Behavior of Soil and Rock Structures

● 5.4-1 Makdisi, F. I. and Seed, H. B., **Simplified procedure for estimating dam and embankment earthquake-induced deformations,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT7,* Proc. Paper 13898, July 1978, 849–867.

This procedure uses the concept of yield acceleration but is based on the dynamic response of the embankment rather than on rigid body behavior. The yield accelerations for a potential sliding mass are estimated on the basis of the static undrained shear strength (with some reduction due to the effects of cycling) using pseudostatic methods of stability analysis. The permanent deformations are estimated by numerical double integration of the time history of induced accelerations for various depths of the potential sliding mass. Design curves are presented based on finite element response computations of embankments subjected to base accelerations representing earthquakes of magnitudes ranging between 6 1/2 and 8 1/4. The simplified procedure is illustrated by an example computation. The permanent deformations are estimated for a 135-ft (40-m) high sandy clay embankment that was shaken by a magnitude 8 1/4 earthquake, and the results are compared with the observed field behavior.

● 5.4-2 **Los Angeles Reservoir is safe from earthquakes,** *Civil Engineering, ASCE,* **48,** *6,* June 1978, 88–89.

The Los Angeles Reservoir replaces the Lower Van Norman Reservoir, whose embankment was damaged by the 1971 San Fernando earthquake. Impounded behind a new earthfill dam, the reservoir provides regulatory and emergency storage for the Los Angeles water supply. Dynamic finite element analysis showed the dam can withstand even the most severe earthquake and still retain the water behind it.

● 5.4-3 Eisler, L. A., Eskin, Ju. M. and Krasnikov, N. D., **Calculation of an earth dam stress-deformation state under seismic effects with account of elasto-plastic soil properties,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-49, 1978, 367–372.

An algorithm and a numerical calculation by the finite difference method of the static and dynamic stress states of earth dams under seismic motion are developed by applying to soil a model of an ideally plastic medium. An example of a 70 m high dam on a rigid (rock) foundation with movements prescribed by an earthquake accelerogram is presented.

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● **5.4-4** Abdel-Ghaffar, A. M. and Scott, R. F., **Dynamic characteristics of an earth dam from two recorded earthquake motions,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 1037–1049.

An investigation has been made of the effect of two earthquakes (with M_L = 6.3 and 4.7) on a modern rolled-fill earth dam. The purposes of the investigation are (1) to study the nonlinear behavior of the dam, (2) to provide data on the in-plane dynamic shear moduli and damping factors for the materials of the dam during real earthquake conditions, and (3) to compare these properties with those indicated by laboratory investigations, and commonly used in dynamic analyses.

● **5.4-5** Breaban, V. and Barbat, H., **Improved finite element analysis for computing the seismic response of dam-reservoir systems,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-58, 1978, 439–444.

The dam-reservoir interaction problem is analyzed for earth dams in which the upstream face is usually very flat. The complete dam-reservoir system is represented by a finite element assemblage. The liquid is represented as a unique elastic, isotropic, and homogeneous continuum. Finite elements, with characteristics which take into account the solid-liquid interface phenomena, are used to represent the dam-reservoir and liquid-ground interfaces. Results and conclusions are given.

● **5.4-6** Negoita, A. and Breaban, V., **Complete earthquake analysis of the dam-foundation ground system,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-59, 1978, 445–450.

The paper presents an analytical procedure for the dam-foundation interaction problem based on the substructure approach and the finite element method. The procedure considers the interaction to be the distortion phenomenon of the free surface seismic ground motion caused by the presence of the structure. The analysis is performed in two stages: first, for the foundation and, then, for the dam substructures. Numerical results are given for an earth dam, using data from the 1977 Romanian earthquake and the 1952 Taft earthquake.

● **5.4-7** Manojlovic, M. *et al.*, **Seismic stability analysis of a slope with soil-structure interaction,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-15, 1978, 107–114.

The paper presents a numerical analysis of dynamic stresses and strains in a soil-structure system with a low safety factor for sliding.

● **5.4-8** Tolkachev, G. S., **Vibration of a nonlinear-elastic layer resting on a rigid foundation,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-05, 1978, 29–32.

Results are presented of the calculation of vibrations of a nonlinear, elastic soil layer resting on a rigid (rock) foundation which is subjected to harmonic displacement. The amplitude-frequency characteristics of surface vibrations of the layer and the distribution of the displacements and deformations over the depth of the layer are obtained. The results for a nonlinear, elastic layer and for a linear, elastic dissipative layer are compared. The inclusion of actual soil properties in the calculations reduces the resonant frequency values. The distribution of the displacements with depth of the nonlinear, elastic layer is within several percent; however, the distribution differs slightly from that of the elastic vibration modes.

● **5.4-9** Pyke, R. M., Knuppel, L. A. and Lee, K. L., **Liquefaction potential of hydraulic fills,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT11,* Proc. Paper 14133, Nov. 1978, 1335–1354.

The potential for future earthquake-induced liquefaction in the hydraulic fills of the port areas of Los Angeles and Long Beach is examined with the aid of several recently proposed, detailed, and simplified procedures. The validity of these procedures is assessed by applying them in a liquefaction analysis of the hydraulic fills existing in the harbor area during the 1933 Long Beach earthquake. The study suggests that there is less than a 50% chance of liquefaction occurring during the useful lifetime of these facilities. The consequences of liquefaction will depend on the nature of land use at the time.

● **5.4-10** Yanagisawa, E., **Response characteristics of embankment including foundation interaction** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 100, Nov. 1978, 793–800.

This study investigates the response characteristics of an embankment constructed on a layered foundation and evaluates the dynamic interaction between the embankment and the foundation. In order to simplify the problem, the embankment is assumed to have a cross section of isosceles triangles and to be based on a soft clay layer. The soil-structure system is assumed to be linearly elastic and only horizontal displacement is studied. Considering two waves in the ground, which are vertically ascending and descending, the amplitude and phase differences at any

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point of the system can be calculated in terms of sinusoidal input wave amplitude. Interaction between the dam and the foundation is described in terms of an equation, in which the effects of the dam body or the ground can be easily recognized.

System resonant frequencies, which do not necessarily coincide with the natural frequencies of the dam body or of the ground, are mainly influenced by shear wave velocities of the surface layer and the embankment. The magnification factor, defined by the maximum ratio of the response at the crest to the base rock motion, varies with the impedance ratios. The influence of the thickness of the surface layer on resonant frequency and the magnification factor is studied. This theory is applied to a multilayered system in order to compare the theoretical results with observed values of microtremors and earthquakes at Hachirogata reclamation dikes in Akita Prefecture. Close agreement between observed and theoretical mode shapes and resonant frequencies was found.

● **5.4-11** Sadigh, K., Idriss, I. M. and Youngs, R. R., **Drainage effects on seismic stability of rockfill dams,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 802-818. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A simplified method is presented for incorporating the effect of drainage in seismic stability computations for rockfill dams. The method is intended to supplement current dynamic analysis procedures, which are primarily applicable to undrained field conditions. In the proposed method, the effects of drainage are considered by making simplifying assumptions with regard to (1) dissipation of excess pore-water pressures within the embankment, and (2) cyclic strength characteristics of embankment materials under partially drained conditions. This provides a convenient and reasonably adequate basis for arriving at a more realistic assessment of the seismic stability of rockfill dams. However, where more accurate results are required, more elaborate analysis procedures can be incorporated for computing the distribution of excess pore-water pressures in conjunction with appropriate laboratory procedures for conducting partially drained cyclic strength tests.

● **5.4-12** Ramanujam, N., Holish, L. L. and Chen, W. W. H., **Post-earthquake stability analysis of earth dams,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 762-776. (For a full bibliographic citation, see Abstract No. 1.2-11.)

An approach to post-earthquake stability analysis of earth dams is presented. First, a finite element evaluation of the dynamic stresses induced within a dam as a result of an anticipated earthquake is determined. Then, the residual undrained static shear strength after the earthquake is determined from laboratory static triaxial tests on soil samples subjected to cyclic loading. The cyclic loading used corresponds to the dynamic shear stresses and the equivalent number of cycles induced in the critical element as a result of the anticipated earthquake. Finally, a limit equilibrium analysis is performed using the residual undrained static shear strength to evaluate the post-earthquake stability of the dam. In some cases, post-earthquake stability is more critical than stability during the earthquake.

● **5.4-13** Vrymoed, J. L. and Calzascia, E. R., **Simplified determination of dynamic stresses in earth dams,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 991-1006. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The dynamically induced shear stresses computed by dynamic finite element techniques are compared to a simplified method using a shear wave propagation technique for the analysis of earth dams during earthquake loading. Even though the simplified technique assumes a horizontally layered deposit, the technique is shown to compare favorably with the dynamic finite element technique. The comparisons show that the simplified technique can be used to adequately determine the dynamic stresses in an earth dam during earthquake loading.

● **5.4-14** Singh, M. P. and Khatua, T. P., **Stochastic seismic stability prediction of earth dams,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 875-889. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A method based on stochastic principles is presented for predicting the seismic stability of earth dams. The problem of nonlinearity because of strain-dependent soil properties is solved through the stochastic linearization technique; a formulation for applying this technique to a finite element discretization of a dam is developed. The method is iterative and step-wise linear. Stochastic description of seismic input in terms of spectral density function can be conveniently used. The method can also be used directly with the ground response spectra curves usually prescribed in seismic designs. The concept of linear cumulative damage is used to define failure. Zero crossing and peak statistics of the stress response are used to define the statistics of cumulative damage. The damage is related to the safety factor which is conventionally used with civil engineering structures. The application of the method is demonstrated with an example earth dam.

● **5.4-15** Makdisi, F. I., Seed, H. B. and Idriss, I. M., **Analysis of Chabot Dam during the 1906 earthquake,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 569-587. (For a full bibliographic citation, see Abstract No. 1.2-11.)

In recent years, a dynamic analysis approach has been proposed for the analysis of the seismic stability of earth dams and embankments during earthquake loading conditions. This approach has been used to analyze the failure of the Sheffield Dam during the 1925 Santa Barbara earthquake and the slides in the San Fernando dams during the 1971 earthquake. This paper examines the applicability of the dynamic analysis procedure by evaluating the behavior of the Chabot Dam under conditions similar to those of the 1906 earthquake. The Chabot Dam is an earthfill dam located south of Oakland, California, approximately 20 miles from the San Andreas fault. This dam was shaken severely by the 1906 San Francisco earthquake but did not suffer any serious damage. Extensive field and laboratory tests were performed and used in the analysis. The resulting element strain potentials are computed and an approximate finite element procedure is used to integrate these strain potentials into an overall embankment deformation pattern. The computed deformations were found to be in reasonable agreement with the behavior of the embankment during the 1906 earthquake. The usefulness and limitations of the analysis are also discussed.

● **5.4-16** Moss, P. J. and Carr, A. J., **The dynamic soil-structure interaction on bridge sites,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 145-149.

This paper presents the results of a series of analyses carried out to study the effects of a variety of valley shapes on the seismic behavior of valleys. The method of analysis used a refined finite element formulation and both horizontal and vertical seismic accelerations could be used as input to the model. In addition to describing the probable seismic behavior of a range of idealized river valleys, the results of analyses of two actual valleys are discussed, with particular reference to the differential horizontal movement that could occur across the top of the valleys under the influence of two earthquakes.

● **5.4-17** Klohn, E. J. *et al.*, **Simplified seismic analysis for tailings dams,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 540-556. (For a full bibliographic citation, see Abstract No. 1.2-11.)

This paper presents a method for approximating the increases in pore pressures that might be expected within a dam or embankment during an earthquake, with particular reference to sand-fill tailings dams. Characteristics of sand-fill tailings dams that are significant to the liquefaction phenomenon are described. Detailed steps are presented for using the method in conjunction with a conventional pseudo-static form of stability analysis. Attention is given to suddenly applied, undrained shear loadings within a tailings dam occasioned by sudden liquefaction of the tailings in the pond at the outset of an earthquake. The principal approximations entailed in the method are discussed.

● **5.4-18** Hampton, M. A. *et al.*, **Quantitative study of slope instability in the Gulf of Alaska,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3314, 1978, 2307-2318.

Large submarine sediment slides occur on the continental shelf and upper continental slope in the Gulf of Alaska. Detailed geological and geotechnical studies of five individual slides point out the significant controls on slope instability. For two slides on the upper continental shelf adjacent to the Kodiak shelf in the western Gulf, it is found that removal of slope support by faulting, augmented by seismic ground accelerations and possibly tectonic slope steepening, controls sediment failure. In the northeastern Gulf, slides on the Copper River prodelta, in Kayak Trough, and off Icy Bay-Malaspina Glacier occur because the sediments are underconsolidated because of high sedimentation rates, seismic accelerations, and wave loading. The presence of free interstitial gas may contribute to instability on the Copper River prodelta and in Kayak Trough. Wave loading should be important in water depths less than 150 m.

● **5.4-19** Serff, N. *et al.*, **Earthquake induced deformations of earth dams,** *EERC 76-4,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 159. (NTIS Accession No. PB 292 065)

A finite element method for calculating the earthquake-induced deformations of an earth dam has been developed and applied to a study of the deformations induced in the upper San Fernando Dam during the earthquake of Feb. 9, 1971. The calculated deformations are in reasonable agreement with the displacements measured after the earthquake, and the calculated stresses and strains explain some of the observed effects of the earthquake on the dam, such as cracking in the outlet conduit and the development of slide scarps on the upstream slope. The method complements the existing procedure for the dynamic analysis of earth dams proposed by Seed et al. in 1973 and appears to provide a reasonable basis for determining permanent deformations in earth dams as a result of earthquake shaking.

● **5.4-20** Franklin, A. G. and Chang, F. K., **Permanent displacements of earth embankments by Newmark sliding block analysis,** *Earthquake Resistance of Earth and Rock-Fill Dams, Report 5, Misc. Paper S-71-17,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Nov. 1977, 59.

In 1965, Newmark described methods for computing permanent displacements of embankments subjected to earthquake loading and provided a chart for estimating the upper bounds of permanent displacements on the basis of a sliding block model and four earthquake records. Since that

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time, many additional strong-motion records have been obtained in the western United States, and it was decided to extend the data base for Newmark's chart by making use of these records. For this purpose, a computer program was written to integrate the digitized accelerograms and compute the permanent displacements from the velocity-time history and the resistance coefficients. All records were scaled to 0.5 g peak acceleration and 30-in./sec peak velocity, and the resulting scaled permanent displacements are called standardized maximum displacements. A total of 169 horizontal and 10 vertical corrected accelerograms were processed in addition to several synthetic records.

The greatest standardized maximum displacements, computed from records of the magnitude 6.5 San Fernando earthquake of Feb. 9, 1971, on soil sites were about 1.5 times above Newmark's upper bound, while those for all other earthquakes analyzed were near or below Newmark's upper bound. The maximum values computed from the Jennings et al. synthetic record for a magnitude 8+ earthquake were about 1.7 times higher than Newmark's upper bound. Those for the Seed-Idriss synthetic record fell slightly below those for the Jennings et al. synthetic records. Ten records from rock sites compared with 47 records from soil sites indicate that permanent displacements on rock sites are about 75% of those on soil sites from earthquakes of the same magnitude, peak acceleration, and peak velocity. It was found that standardized maximum displacements are roughly proportional to the duration of shaking and, consequently, are positively correlated with earthquake magnitude. Appendixes A and B list the earthquakes and the ground motion data used, respectively. Appendix C presents data on the synthetic records.

● 5.4-21 Abdel-Ghaffar, A. M. and Scott, R. F., **An investigation of the dynamic characteristics of an earth dam,** *EERL 78-02,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Aug. 1978, 194.

This paper describes an investigation made to analyze observations of the effect of two earthquakes (with M_L = 6.3 and 4.7) on the Santa Felicia Dam, a rolled-fill embankment located in southern California. The dam is 236.5 ft high and 1275 ft long by 30 ft wide at the crest. The paper (1) studies the nonlinear behavior of the dam during the two earthquakes, (2) provides data on the in-plane dynamic shear moduli and damping factors for the materials of the dam during actual earthquake conditions, and (3) compares these properties with those previously available from laboratory investigations.

From the recorded motions of the dam, amplification spectra are computed to indicate the natural frequencies of the dam and to estimate the relative contribution of different modes of vibrations. A comparison between these natural frequencies and those obtained by two elastic shear-beam models is made to obtain representative dam material properties. Field wave-velocity measurements were carried out as a further check and to study the variation of shear wave velocity at various depths in the dam. The amplification spectra show a predominant frequency of 1.45 Hz in the upstream/downstream direction; in this direction, the response is treated as that of a single-degree-of-freedom hysteretic structure. Three types of digital band-pass filtering of the crest and abutment records are used to enhance the hysteresis loops which show the relationship between the relative displacement of the crest with respect to the abutment and the absolute acceleration of the dam. A method is described, using some of the existing elastic-response theories, which enables the shear stresses and strains, and consequently the shear moduli, to be evaluated from the hysteresis loops. The equivalent viscous damping factors are calculated from the areas inside the hysteresis loops. The shear moduli and the damping factors are determined as functions of the induced strains in the dam. The shear moduli and damping factors obtained for the dam are compared with previously available laboratory data for sands and saturated clays.

5.5 Dynamic Behavior of Foundations, Piles and Retaining Walls

● 5.5-1 Novak, M. and Howell, J. F., **Dynamic response of pile foundations in torsion,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT5,* Proc. Paper 13767, May 1978, 535-552.

A theory is presented which facilitates the evaluation of torsional stiffness and damping of piles embedded in horizontally layered soils. This theory employs the stiffness matrix method and is an extension of a continuum approach presented earlier by the authors. Response curves for piled footings may be calculated using the data in the figures for stiffness and damping. Comparison of theoretical predictions with results of field experiments shows good agreement. Dynamic properties of piles are found to be very dependent on the variation of soil properties with depth and on soil material damping. The importance of soil material damping is also demonstrated for shallow rigid footings vibrating in the torsional as well as the rocking modes.

● 5.5-2 Ismael, N. F. and Klym, T. W., **Behavior of rigid piers in layered cohesive soils,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT8,* Proc. Paper 13969, Aug. 1978, 1061-1074.

Full-scale tests were carried out on two instrumented rigid piers installed in a firm cohesive layered subsoil near Hamilton, Ontario. The piers were uplifted to failure and

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laterally loaded under short-term loading conditions. The results are analyzed, and different methods of analysis are examined in this paper. Large uplift parameters caused by the large suction pressures measured below the piers were recorded in the uplift tests. A modification of the nonlinear method of analysis of lateral deflection is proposed for rigid piers because of the good predictions of the foundation behavior. Detailed in-situ and laboratory measurements of the shear strength were made, and the results and conclusions are presented.

● 5.5-3 Lin, Y. J., **Dynamic response of circular plates resting on viscoelastic half space,** *Journal of Applied Mechanics, ASME,* 45, 2, June 1978, 379–384.

Dynamic responses of circular thin plates resting on a viscoelastic halfspace subject to harmonic vertical and rocking excitations are studied. The analysis is based on the assumption that the contact between the plate and the surface of the halfspace is frictionless. This dynamic mixed boundary-value problem leads to sets of dual integral equations which are reduced to Fredholm integral equations of the second kind and solved by numerical procedures. The numerical results show that the rocking impedance function is independent of the plate flexibility but that the vertical excitation is not.

● 5.5-4 Carvalho, E. C., Ravara, A. and Duarte, R. T., **Analytical and model studies for the International Guadiana Bridge,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-30, 1978, 227–234.

Analytical and experimental studies performed for the proposed pile foundation and superstructure of the International Guadiana Bridge are presented. The bridge will connect a village in Portugal with a village in Spain. A description of the structure, its foundation and the geotechnical characteristics of the site are presented. Stresses and internal forces resulting from a 1000-yr return period earthquake are evaluated for the steel-encased concrete pile foundations. This study is the first of its kind conducted by the Lab. Nacional de Engenharia Civil, Lisbon. The main difficulties involved soil characterization and modeling.

● 5.5-5 Prater, E. G., **Dynamic analysis of piles under lateral load,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-11, 1978, 75–81.

The flexural behavior of single piles under conditions of earthquake or lateral impulse loading is investigated, assuming a nonlinear earth resistance of the Winkler foundation type to simulate embedment in an elastoplastic medium of soil layers. An explicit finite difference technique is used to solve the flexural wave equation. The advantages and disadvantages of this system compared with that of halfspace theory or finite element geometrical modeling are discussed.

● 5.5-6 Corsanego, A. *et al.*, **On the solution of the building-to-building interaction under seismic excitation,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-19, 1978, 139–146.

Structure-structure interaction is analyzed by means of a modified semi-analytical solution for surface footings on horizontally stratified soils. The structures are idealized as simple oscillators, and different arrangements of two of these are analyzed and compared.

● 5.5-7 Srinivasulu, P., Lakshmanan, N. and Thandavamoorthy, T. S., **Dynamic analysis of blocks supported on piles,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-14, 1978, 99–106.

A case study of the dynamic behavior of a machine foundation supported on piles is presented. Computations for the dynamic response of the foundation based on three different analytical approaches are explained. The computed amplitudes are compared with the values measured at the site under actual machine-operating conditions, and conclusions are drawn.

● 5.5-8 Tetior, A. N. *et al.*, **Study of effective bored in-situ pile foundation structures for seismic regions,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-12, 1978, 83–90.

● 5.5-9 Aubakirov, A. T. and Erzhanov, S., **Special pile foundations with heightened deformability and dissipative characteristics,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-13, 1978, 91–97.

The behavior of rigid seismic-resistant buildings with pile foundations having high deformation and dissipation capabilities is analyzed. Behavior and response spectra are examined. One degree-of-freedom system dynamic coefficients are obtained based on the quantitative analysis of the accelerograms of six earthquakes of varying intensities. The dynamic characteristics of such systems under static and dynamic loading are determined. From the results, it is concluded that pile foundations with heightened deformability and dissipative performance should be considered in earthquake-resistant design and construction.

● 5.5-10 Shibuya, J. and Shiga, T., **Dynamic response of embedded foundations subjected to incident seismic**

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waves, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 53, Nov. 1978, 417–424.

The dynamic response of embedded foundations subjected to vertically incident seismic waves is analyzed. The soil is modeled as a simple two-dimensional semi-infinite elastic body, and the foundation is represented by a massless rigid strip with a rectangular cross section. The problem is analyzed as a boundary value problem, which is formulated in terms of the coupled integral equations. Numerical solutions are obtained. The dynamic response of the foundation, expressed as the fraction of the free surface response of the soil, is discussed in relation to the exciting frequency of the incident waves and the depth of embedment of the foundation.

● 5.5-11 Akiyoshi, T., Nakayama, U. and Fuchida, K., **Dynamic lateral stiffness of pile groups,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 47, Nov. 1978, 369–376.

The lateral stiffness of pile heads is discussed based on the dynamic interaction between a soil stratum and vertical pile groups. The stiffness is presented in terms of the depth of the soil stratum, the pile spacing, the slenderness ratios, the ratios of the wave velocities of the soil and the piles, and the exciting frequency. The soil stratum surrounding the piles rests on bedrock and is divided into finite triangle or sector prisms for the analysis. This enables the soil stratum to be treated vertically as homogeneous and continuous columns and horizontally as finite elements. This quasi-analytic method simplifies the treatment of this three-dimensional system because no nodal points occur between the surface and the bottom of the soil stratum. The method also simplifies computations of the soil-pile coupled system. To represent the consistent (transmitting) boundary, through which the wave energy that radiates from the pile surfaces is transmitted to the far-field, a simulated circular cylindrical boundary is used for the semi-infinite stratum. Equally divided sector elements along the consistent boundary are used to develop an extended version of Lysmer and Waas's consistent boundary. The computational results show that the dynamic lateral stiffness of a pile head is influenced a great deal by pile spacing, while the variation of pile stiffness is not sensitive to the slenderness ratio of a pile.

● 5.5-12 Noda, S., Chiba, T. and Uwabe, T., **Shaking table tests of a composite breakwater** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 101, Nov. 1978, 801–808.

In order to prevent tsunami damage, a project is under way to construct a large composite breakwater in relatively deep sea of -60 m at a bay mouth. This breakwater consists of a rubblestone mound of 40 m in height and large concrete caissons on top of the mound. Although this breakwater is similar to rockfill dams and embankments, it differs from dams in that most of it is submerged in water and that the mound is made of very permeable material which supports massive concrete caissons. To clarify the seismic resistance of the breakwater on the stable seabed, the authors have carried out model tests on a shaking table. This paper presents the results of experiments and the results of a preliminary analysis of the stability of the composite breakwater.

In consideration of the importance of permeability on the stability of the breakwater, a coarse sand with a suitable coefficient of permeability was chosen for the model mound. The shaking table was excited by a sinusoidal motion (maximum acceleration: 15~100 gals, frequency: 5~50 Hz) and by an earthquake motion (modified Hachinohe S-252 NS, predominant frequency: 3.5~43 Hz). The dynamic behavior of the models was mainly measured by accelerometers and water pressure gauges on the caissons which were buried in mounds.

The following information was obtained. Since sliding and settlement of the caissons and failure of mounds did not occur it was supposed that the test prototype of the breakwater was considerably safe against severe earthquakes with maximum accelerations of 350 gals and less. In case of small table acceleration of about 15 gals, the models showed such a significant dynamic response as rocking of the caissons, and acceleration at the top of the caissons reached 5~15 times table acceleration. However, acceleration at the top of the caissons decreased 3~5 times when table acceleration increased to 50 gals. Although the mounds were made of very permeable material, dynamic pore water pressure was generated and caused a change in the sign of the response. It was supposed that this pore water pressure was generated by an elastic deformation of the mounds. Stability analysis by a circular arc method gave a fairly small factor of safety which did not agree with the actual failure of the models. It was concluded that one of the reasons for the shear strength of the mound not decreasing as much as expected was the negative pore water pressure.

● 5.5-13 Puri, V. K. *et al.,* **Evaluation of dynamic soil-pile constants from in-situ tests,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 349–354.

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The paper describes forced vibration, free vibration, and cyclic lateral load tests conducted on driven cast-in-situ piles 45 cm in diameter and 17 m long. A rational approach is suggested for determination of the overall dynamic stiffness coefficients for a soil-pile system under horizontal vibrational modes for use in the design of machine foundations. It is observed that the horizontal stiffness coefficient and the horizontal subgrade reaction constant depend upon strain amplitude. Stiffness coefficients and reaction constants under static and dynamic conditions are compared. The dynamic values are 20% to 30% of the corresponding static values for the particular soil-pile system of interest to the designer of machine foundations.

● **5.5-14** Ettouney, M. M. and Kar, A. K., **Compliance function of footing in two-layer medium,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 425–440. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The paper presents a set of formulas to determine the complex swaying compliances for rigid footings embedded in a two-layer medium excited by a harmonic forcing function. The bottom layer generally, though not necessarily, consists of rock. The top layer is with or without material damping. The results obtained by using the formulas are compared with "exact" solutions by the finite element and semi-analytical methods. Comparisons between the results of the suggested formulas and the exact solutions show excellent agreement for practical cases. Parametric studies, including the effects of material damping, depth of embedment, and relative shear wave velocities of the two layers, are conducted. The results are applicable to many soil-structure interaction problems.

● **5.5-15** Dawson, A. W., **Soil-structure interaction for footing foundations,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 380–393. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The current state-of-the-art regarding the evaluation of the seismic behavior of footing foundations is largely empirical and deficient in many important aspects. This is undoubtedly a consequence of the apparently satisfactory seismic behavior of most footings where site instability, liquefaction, and seismic compaction have not been a problem. In other words, classical gross bearing failures are seldom observed in areas affected by earthquakes. One purpose of this paper is to illustrate a few ways in which footing foundations may play an important role in modifying structural behavior through soil-structure interaction, even when no obvious foundation failures occur.

Criteria for evaluating the seismic behavior of footing foundations are presented. The ability of columns to transmit moments to footings is evaluated in terms of the relative stiffness of the columns, foundations, and girders. The ultimate moment capacity of the footings and nonlinear soil behavior are considered in this evaluation, and a simple analytical procedure is presented. The implications of varying degrees of column base fixity are discussed in terms of structural behavior and geotechnical footing design criteria. To provide additional criteria for selecting design bearing pressures, the applicability of using traditional bearing capacity equations for seismic loads is examined. The influence of both individual and group footing compliance is discussed so that the consideration of seismic soil-structure interaction effects may be extended to the analysis of footing foundations.

● **5.5-16** Arya, A. S., Puri, V. K. and Prakash, R., **Dynamic response of wells under earthquake loading,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 381-387.

The paper describes a comparison of the dynamic seismic response of a typical bridge pier-well system. Used in the analysis are soil spring stiffness values based upon Terzaghi's concept of subgrade reaction coefficients and elastic halfspace theory. The values of time periods, moments, shear forces, and deflections obtained in the two cases have been compared both for longitudinal and transverse vibrations. It is observed that in the particular case studied the stiffness is underestimated and, consequently, the time periods are overestimated when the subgrade reaction coefficient concept is used. The moments, shears, and deflections also are affected. The results of field tests conducted by other investigators on bridge wells show that the actual stiffness values obtained from free vibration and lateral load tests are several times higher than those obtained from the coefficients of subgrade reaction. It is, therefore, felt that the stiffness parameters for use in the dynamic analysis may be obtained from elastic halfspace theory based upon the values of dynamic shear modulus and Poisson's ratio.

● **5.5-17** Madhav, M. R. and Rao, K. K., **Lateral load capacity of initially bent piles,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 343–348.

Broms has provided a simple solution for finding the lateral resistance of straight vertical piles. Piles may bend from the vertical axis for several reasons. The lateral resistance of bent piles will be less than the resistance of straight piles because of the residual stresses present in the piles. Methods for calculating the lateral loads in all such cases and design charts are presented.

● **5.5-18** Prajapati, A. H. and Char, A. N. R., **Elastic analysis of single batter piles subjected to horizontal loads,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 335–342.

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In the present investigation, an analysis based on an elastic approach is presented for batter piles embedded in noncohesive soils having constant soil moduli and Poisson's ratios with depth. The finite difference technique is used to calculate normal deflections, bending moments, and soil reactions for the piles. Suitable modifications permit three linear variations of soil moduli with depth. The theoretical solutions obtained are compared with available experimental results for model batter piles.

It is shown that the elastic approach employing Mindlin's equation can be extended to study the behavior of batter piles. The solutions for the deflection and bending moment agree well with the experimental results for mild batters if a constant soil modulus is assumed, even though the modulus overestimates the maximum soil reactions. For the assumptions of hydrostatic variation of soil modulus with depth, the deflection and bending moment are overestimated but the soil reaction is realistically distributed along the pile.

● 5.5-19 Fukuoka, M., **Interaction problems of well foundation and piers,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 537-556.

The earthquake-resistant design for well foundations proposed by Mononobe after the 1923 Kanto earthquake and the design revised by the Japanese National Railways are described. The experimental studies, measurements, and analyses conducted by various institutions in Japan are mentioned. These studies mainly concern the planned Honshu-Shikoku bridges. Many comparisons have been made of the analytical results found using mechanical models, the soil constants obtained by in-situ tests, the dynamic tests on core samples, and the observation results of actual vibration tests of caissons and the vibrations of ground and caissons during earthquakes. Satisfactory comparisons have not been achieved. It is suggested that future research concentrate upon the explanation and forecast of actual phenomena.

● 5.5-20 Pise, P. J., **Experimental coefficients for laterally loaded piles,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 327-333.

Model tests have been carried out on a single pile under lateral loading and on pile groups under lateral and vertical loading. A sand uniformity coefficient of 1.1 has been used as a foundation medium. The flexural behavior of the piles and the variation of the subgrade modulus along the embedded portion of the piles have been investigated. Typical test results for a single pile and for a 1 x 2 pile group are presented. The subgrade modulus for sand is found to increase nonlinearly with depth. Generalized solutions are presented for a pile unrestrained at its top; the pile is subjected to lateral load and moment from observed data of soil-pile interaction. The plots of more general nondimensional coefficients obtained from the actual behavior of piles under different testing conditions are presented. The observed behavior of piles reported by other researchers is compared with the behavior predicted using the author's coefficients. The observed and predicted values are in very good overall agreement.

● 5.5-21 Agarawala, S. K. *et al.*, **Analysis of single and group piles,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. II [1977], 63-70.

Single and group piles have been analyzed by means of a finite element technique using a bar element on an elastic foundation. The variations of axial and transverse displacements of the element have been assumed to be parabolic and cubic, respectively, and, by employing the method of static condensation, the degrees-of-freedom at the two end nodes have been reduced to six. The element can be assumed to be curved. A detailed discussion and treatment of two moduli (lateral subgrade reaction and tangential subgrade reaction) are presented. To improve the subgrade representation, the layered foundation model and the infinite element concept recently incorporated into the computer program used in the analysis is briefly discussed. The problems of vertical and initially bent single piles are solved and the results are compared with available experimental and analytical results. Two problems for group piles lying in a two-dimensional plane are solved and the results compared with analytical results. The discrepancies and the agreements between the results are explained.

● 5.5-22 Sinha, K. N., Bagchi, J. K. and Iyenger, M., **Dynamic response of reciprocating compressor blocks on bored piles,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 437-444.

Dynamic analyses are conducted of block foundations supporting a pair of highly unbalanced reciprocating compressors and of a similar compressor block foundation. Both these block foundations rest on cast-in-place bored piles.

● 5.5-23 Savidis, S. A. and Richter, T., **Dynamic interaction of rigid foundations,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/36, 1977, 369-374.

The interaction of two buildings on rigid, rectangular foundations is investigated. The displacement boundary conditions at the base of the foundations are satisfied at discrete points. For this purpose, the foundations are

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subdivided into finite elements and the dynamic soil pressure is assumed to be constant. After the displacement matrix for the massless foundation is calculated, the magnification functions of the foundations with masses are determined. For the special case of two square, symmetrically arranged foundations of the same size, the magnification functions are considered to be dependent on the frequency and the dimensionless mass factors of both foundations. This consideration is made because of the constant, harmonic, vertical excitation of the first foundation. In a second investigation, the influence on the magnification functions is established for three different forms of a foundation not subjected to excitation.

● **5.5-24** Aggour, M. S. and Brown, C. B., **Resonance of retaining walls,** *Engineering Structures,* **1,** *1,* Oct. 1978, 3–7.

This paper considers the two-dimensional problem of a flexible retaining wall and deformable fill excited at resonance within input limits suggested by Drenick. The analysis is within the field of damped elasticity and the solution is by a conventional finite element program. The results are in the form of stresses and displacements; in particular, the form of the dynamic pressure on the wall is provided. Parametric studies for various fill geometries and characteristics as well as wall forms are developed. A crucial initial problem is that the interface conditions between the wall and fill be specified.

● **5.5-25** Myslivec, A. and Kysela, Z., **The bearing capacity of building foundations,** *Developments in Geotechnical Engineering, Vol. 21,* Elsevier Scientific Publishing Co., New York, 1978, 237.

The book contains chapters on the following subjects: settlement of foundations; bearing capacity of foundations (including the shearing resistance of soils under seismic loads); permissible loads on foundations; and stresses in soils beneath building foundations. Also included are a bibliography, an index, and two appendixes. Appendix I gives tables for the determination of the vertical stresses in soils; appendix II presents methods for the determination of the active zone during the calculation of the settlement of buildings.

5.6 Experimental Investigations

● **5.6-1** Koutsoftas, D. C., **Effect of cyclic loads on undrained strength of two marine clays,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT5,* Proc. Paper 13751, May 1978, 609–620.

Specimens were first isotropically consolidated, then subjected to stress-controlled cyclic loading, and finally monotonically loaded to failure. Tests were conducted on normally consolidated specimens and on overconsolidated specimens with an overconsolidation ratio of 4. Comparisons with the results of standard undrained triaxial compression tests indicate that cyclic loading prior to undrained shear causes a small reduction in undrained shear strength and a significant reduction in undrained modulus. Excess pore-water pressures generated by cyclic loading were also found to correlate well with the double amplitude strain induced by cyclic loading. A reduction in effective stress is associated with the excess pore pressures. The decrease in effective stress is largely responsible for the reduction in undrained shear strength after cyclic loading.

● **5.6-2** Martin, G. R., Finn, W. D. L. and Seed, H. B., **Effects of system compliance on liquefaction tests,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT4,* Proc. Paper 13667, Apr. 1978, 463–479.

A theoretical analysis is presented of the errors arising from volumetric compliance in cyclic liquefaction tests on saturated sands. For cyclic simple shear tests, compliance occurs with changes in membrane thickness, membrane stretch in corners, and expansion of the confining frame as pore-water pressures increase. For cyclic triaxial tests, compliance arises from reductions in membrane penetration. Compliance is shown to cause significant increases in stress ratios causing initial liquefaction. For triaxial tests, computations indicate that measured increases in stress ratios causing initial liquefaction with increase in grain size are primarily attributable to the effects of membrane penetration. The compliance effect arising from partial saturation is also examined, and significant increases in stress ratios causing initial liquefaction with only small reductions from full saturation are shown to occur. The difficulties of eliminating the effects of system compliance from undrained liquefaction tests suggest the use of constant volume simple shear liquefaction tests where drained samples are tested under constant volume conditions.

● **5.6-3** Lee, K. L. and Vernese, F. J., **End restraint effects on cyclic triaxial strength of sand,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT6,* Proc. Paper 13839, June 1978, 705–719.

Cyclic triaxial tests were performed on various soils at different densities and different consolidation pressures, using regular and lubricated ends to explore the possible effect of end restraint. In addition, a number of supplementary tests were performed, all of which led to the conclusion that for the sands tested, the following factors had no measureable effects on the cyclic triaxial strengths: cyclic frequency, load shape, small center dowels at the ends, and sample diameter. The end restraint study showed that the cyclic strength was greater for frictionless ends than for regular ends by amounts ranging from zero for nondilatant soils to as much as 35% for dense, very dilatant sands. For the usual cases of loose to medium dense sands for which cyclic tests are most frequently performed, the apparent

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strength increase is only about 10%, which has already been included in the C_r factor for converting cyclic triaxial results to field strengths.

● **5.6-4** Finn, W. D. L., Vaid, Y. P. and Bhatia, S. K., **Constant volume cyclic simple shear testing,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 839-851.

Compliance in systems during undrained cyclic shear tests on saturated sands is equivalent to partial drainage; this can have a significant effect on the measured liquefaction potential. A new "constant volume" cyclic simple shear test has been developed in which compliance is limited to low values. This paper describes the new test system and an improved method of sample preparation. Data from the new equipment are compared with cyclic simple shear data from conventional equipment to show directly the effect of system compliance. Lateral as well as vertical stresses are measured during cyclic loading.

● **5.6-5** Umehara, Y. and Zen, K., **Correlations of liquefaction resistances based on static and dynamic triaxial tests and vibration table tests,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 79, Nov. 1978, 625-632.

The liquefaction resistance of saturated sands may be evaluated by various types of test methods. It would be of value to determine correlations among the methods. This paper describes correlations of dynamic and static triaxial test results and correlations of dynamic triaxial test results and vibration table test results.

● **5.6-6** Ranjan, G. and Tyagi, G. R. S., **Piles under vertical and horizontal cyclic loads in sand,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 369-374.

The paper discusses the behavior of a single vertical pile model under constant vertical and cyclic lateral load. The tests have been carried out using 1.2 cm diameter aluminum rods embedded in noncohesive soil with a relative density of 65%. A special cam arrangement has been used to apply cyclic loads in single steps. Records of vertical and horizontal displacements have been taken. Cycles of loading up to 500 have been applied. Various combinations of vertical load and cyclic horizontal load have been used. The test results indicate that (a) Up to about 100 cycles, cyclic loading rapidly increases the vertical displacement and horizontal displacement of a single pile; beyond 100 cycles, the increase in displacement rates is much less. (b) The soil modulus appears to increase under cyclic loading up to a certain magnitude of applied horizontal load beyond which the modulus tends to remain practically constant.

● **5.6-7** Chaney, R. C., **Saturation effects on the cyclic strength of sands,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 342-358. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The effect of the degree of saturation (expressed in terms of B-values) on the cyclic response of compacted specimens of Monterey No. 20-30 sand was investigated using cyclic triaxial test methods. Standard stress-controlled cyclic triaxial tests were conducted on specimens exhibiting a high degree of saturation, and cyclic triaxial tests with pulsating axial and lateral pressures were performed on samples at lower degrees of saturation. Specimens were tested at two relative densities (53% and 93%) and at varying degrees of saturation (B-values from 0.67 to 1.00). Test results indicate that degrees of saturation in excess of 99.0% for both loosely and densely compacted specimens must be achieved before liquefaction occurs in less than 1000 cycles of loading for any stress ratio studied.

Typical results, which define pore-pressure response and double-amplitude axial strain versus the logarithm of the number of cycles of load application for various stress ratios, are presented. These results show that the number of cycles required to achieve a specified strain at a constant cyclic stress ratio increases with decreasing B values (decreasing degrees of saturation). A linear relationship was observed for both loose and dense specimens when B values were plotted as a function of the logarithm of the number of cycles of load application required to achieve 5% double-amplitude strain for both loose and dense samples. Results also indicate that low B-values had a greater effect on the cyclic strength of soils under a low-cyclic stress ratio than under a high-cyclic stress ratio for both loosely and densely compacted sands. Results from this study are shown to agree qualitatively with data previously presented by Rocker. In addition, results are also explained in a qualitative manner using the liquefaction concepts developed by Martin et al.

● **5.6-8** Chae, Y. S. and Chiang, J. C., **Dynamic properties of lime and LFA treated soils,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 308-324. (For a full bibliographic citation, see Abstract No. 1.2-11.)

This paper reports an experimental investigation of the dynamic properties of lime- and lime-fly ash treated soils. In treating weak clay soils and structurally unstable granular soils to support foundations subjected to earthquake or other forms of dynamic loading, the advantages of using soils treated with additives have not been fully utilized. The purpose of this investigation was to provide information on the dynamic properties of soils treated with additives. The two soils, a uniform sand and a silty clay, were treated with lime- and lime-fly ash. The dynamic shear moduli and damping for both soils were determined by the resonant column technique. Test variables studied were treatment level (additive content), confining pressure, shear-strain amplitude, and moisture content. These four variables were found to have the most profound effects on the dynamic properties. Static triaxial compression tests were also run on the same specimens to correlate dynamic properties with static strength values. Eighty-eight specimens were analyzed. With various combinations of the test variables considered, approximately 1800 tests were performed.

It was found, in general, that the dynamic shear moduli of sand and silty clay could be greatly increased by small amounts of additives. The effect of confining pressure, which increased the dynamic shear modulus and decreased the damping, was more pronounced in treated noncohesive soils than in cohesive soils. Higher shear-strain amplitude reduced the dynamic shear modulus with the maximum dynamic modulus obtained at zero strain amplitude. Treatment with additives increased the rate of change of the dynamic shear modulus with strain amplitude for noncohesive soils, while the opposite was true for cohesive soils. The moisture content had a significant effect on the dynamic properties of treated cohesive soils, but had no appreciable influence on treated noncohesive soils. For practical purposes, the maximum dynamic shear modulus could be predicted by the static shear strength of the soils. However, no such correlations were obtained between the damping characteristics and the static strength of the soils.

● **5.6-9** Stokoe, K. H. and Lodde, P. F., **Dynamic response of San Francisco Bay mud,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 940–959. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Shear moduli and material damping of undisturbed samples of San Francisco Bay mud were investigated in the laboratory by the resonant column method. These properties were studied over a range of single-amplitude shearing strains from 0.0002 to 0.2% and over a range of confining pressures from 2.5 to 80 psi. It was found that, below a threshold shearing strain of about 0.001%, shear modulus and material damping of Bay mud are essentially independent of shearing strain amplitude. Above the threshold shearing strain, modulus decreases and damping increases as strain increases. Confinement time is an important parameter in the determination of the dynamic properties. Shear modulus continually increases and material damping continually decreases with increasing time at a constant confining pressure at shearing strains below the threshold strain. An increase in shear modulus with time of constant confinement also occurs in Bay mud at shearing strains as high as 0.1% and this increase is similar to that measured at low-amplitude strains. Cycling for 1000 cycles or less below a threshold degradation strain level of 0.01% has essentially no effect on the dynamic properties of Bay mud. However, cycling above this threshold degradation level causes a temporary decrease in modulus and an increase in damping. The dynamic properties of the Bay mud rebound with time after high-amplitude cycling to the original properties as evaluated by the long-term time effect. A close comparison between laboratory and published field shear wave velocities is found when the long-term time effect is taken into account.

● **5.6-10** Salomone, L. A., Singh, H. and Fischer, J. A., **Cyclic shear strength of variably cemented sands,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 819–835. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The Vincentown formation of New Jersey is a stratigraphic unit of Tertiary age within the New Jersey coastal plain. Initial laboratory test results of the Vincentown formation indicate an appreciable difference in cyclic strengths between undisturbed and reconstituted samples. In addition, many samples showed very high cyclic shear strengths, although the relative densities were comparably low. Because these properties are not normally associated with consolidated or unconsolidated sands, a detailed laboratory and field study was conducted. The purpose of the study was to evaluate the in-situ physical state of the sands and relate these results to the dynamic properties obtained in the laboratory.

The properties of the Vincentown formation, a cemented, silty, fine-to-medium sand, were studied by means of field observations and laboratory triaxial CIUC tests and cyclic triaxial liquefaction tests. In addition, petrographic analyses of the Vincentown formation were conducted to explore the mineralogy and physical properties of the sedimentation and to evaluate to what extent diagenetic processes have affected these initially unconsolidated coastal plain sediments.

The results indicate that the apparent anomalous strength properties observed in both static and dynamic tests are clearly attributable to the inherent structure of the formation, which was controlled by the manner in which the sediments and subsequent calcareous cementation were deposited. Traditional methods of evaluating cyclic shear strength need to be reevaluated when applied to cemented soils. It was found that care must be exercised in selecting samples of soils of this type to minimize the disturbance effect, since test results are sensitive to the sampling method used in the field.

● **5.6-11** Shen, C. K. *et al.*, **Dynamic response of a sand under random loadings,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 852–863. (For a full bibliographic citation, see Abstract No. 1.2-11.)

This paper summarizes a laboratory investigation of undrained triaxial specimens of fine sand compacted to different densities and subjected to random loading conditions. During the application of the random load, the pore water pressure and axial deformation which developed were recorded. All tests were carried out with an electrohydraulic closed-loop system using a magnetic tape data recorder to control the random load applied. Identical soil specimens were tested using four different random load time traces. These traces can be converted to the same equivalent number of significant uniform stress cycles as outlined by Lee and Chan. Based on the results of this investigation, the effect of loading path dependency on dynamically loaded specimens is evaluated, and the concept of using a significant number of equivalent stress cycles to approximate the random field seismic loading conditions is examined.

● **5.6-12** Marcuson, III, W. F. *et al.*, **Effect of load form and sample reconstitution on test results,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 588-599. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Because of the slide in the Lower San Fernando Dam during the San Fernando earthquake of Feb. 9, 1971, the U.S. Army Corps of Engineers began earthquake studies of hydraulic fill dams located in seismically active areas. Among these studies is a dynamic analysis of Sardis Dam. This paper presents the results of dynamic laboratory tests performed on undisturbed and reconstituted samples. The undisturbed samples were taken with a Hvorslev fixed-piston sampler. A number of the samples were drained and frozen before they were taken to the laboratory; the remaining samples were drained and tapped before they were taken. Isotropically and anisotropically consolidated cyclic triaxial tests were performed on undisturbed and reconstituted samples of the shell and foundation material. Cyclic triaxial tests were also performed on undisturbed samples of the core material. A special series of cyclic triaxial tests was conducted to evaluate the influence of (1) square and sine wave loading, and (2) specimen reconstitution.

It was found that specimen reconstitution had no effect on the shell material and increased the dynamic strength of the foundation material approximately 33%. Sine and square wave loadings produced about the same results for the shell material; however, foundation materials were found to be sensitive to wave form. It is noted in conclusion that the foundation data produced with the square wave must be multiplied by a factor of 0.8 to make it equal to the sine wave data.

● **5.6-13** Wright, D. K., Gilbert, P. A. and Saada, A. S., **Shear devices for determining dynamic soil properties,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 1056-1075. (For a full bibliographic citation, see Abstract No. 1.2-11.)

This paper examines the state of the specimen in some of the more popular shearing devices used for dynamic (and static) soil testing. The conditions prevailing in the hollow cylinders used by Ishihara, Lade, and Sherif are briefly discussed and compared; the importance of the proper ratio between height and thickness and height and mean diameter is emphasized. A relatively detailed study of the simple shear devices of the Roscoe type and of the NGI type is made. The results of a three-dimensional photoelastic study based on the frozen stress technique are presented and compared to those obtained from published finite element analyses. The results show that the claim regarding the uniformity of the shearing stresses on the central plane in the NGI device is unwarranted and that the conditions are slightly more acceptable in the Roscoe device. Recommendations are made regarding the conditions to be satisfied by testing machines to avoid undesirable end effects.

● **5.6-14** Wong, I. H., Abdelhamid, M. S. and Fischer, J. A., **Compaction and cyclic shear strength of granular backfill,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 1042-1055. (For a full bibliographic citation, see Abstract No. 1.2-11.)

A compacted, granular, coarse-to-fine sand with varying gravel content is used as structural backfill below and around major structures for an industrial facility in southern New Jersey. It is important that the backfill for the major structures performs well under the design earthquake loading. This paper summarizes the index properties as well as the cyclic shear strength of laboratory-compacted samples of the granular backfill material. In addition, it discusses the criteria utilized in selecting this material as a suitable structural backfill. Index properties investigated included grain size distribution, specific gravity, maximum and minimum densities, and moisture density relationships based on modified Proctor compaction tests. The effect of "scalping" on the results of the compaction tests and cyclic strength tests is also discussed. The degree of compaction of the tested soils is based on percent of compaction rather than on relative density. The rationale behind this approach is outlined in the paper.

Compacted samples for dynamic testing were prepared using wet tamping and the concept of under-compaction. Samples were compacted to 95 and 98% of the maximum dry density based on modified Proctor compaction test results. A series of cyclic triaxial liquefaction tests was performed at different shear stress ratios, confining pressures, and principal stress ratios during consolidation. The results are presented in the form of a cyclic shear stress ratio versus the number of cycles to failure. The cyclic

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shear strength of the samples compacted to 98% of the maximum dry density, based on the modified Proctor tests, was significantly higher than those compacted to 95% of the maximum dry density.

● **5.6-15** Herrmann, H. G. and Houston, W. N., **Behavior of seafloor soils subjected to cyclic loading,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. III, OTC 3260, 1978, 1797-1808.

An extensive laboratory cyclic triaxial test series was carried out on undisturbed samples of six offshore soils, most from deep ocean. Consolidated, undrained stress-controlled tests were performed at a frequency of 2 Hz for either 300,000 loading cycles or until failure. Pure stress reversal, partial stress reversal, and large static bias loading conditions were used. Based on analyses of the static behavior and cyclic behavior at smaller numbers of loading cycles, these soils are quite similar in behavior, with the possible exception of the two calcareous oozes investigated, to the behavior of other nearshore and terrestrial soils summarized in the literature.

The major effects of the stress system (the extent of static bias) on strength under cyclic loading, secant modulus, and accumulation of strain are illustrated. The behavior of soils under large numbers of cycles is documented in detail, with emphasis on non-failing loading conditions. Relationships between modulus variation, strain amplitude, pore pressure response, cumulative axial strain, and failure conditions are presented. Several criteria are suggested for avoiding loading conditions leading to degradation of soil properties. It is demonstrated that, if soils are loaded sufficiently below failure conditions, the continuous decrease in modulus (documented by others using smaller numbers of loading cycles) does not continue indefinitely and, in fact, the modulus will typically rebound slightly, implying that the sample will not ultimately fail at even much larger numbers of loading cycles than the 300,000 used in this experimental study. The results of this study are applicable to anchors, foundations, and slopes subjected to combinations of static and cyclic loading under undrained conditions, and where soil properties and stress levels are similar to those of the eight soils used in this study.

● **5.6-16** Shen, C. K., Vrymoed, J. L. and Uyeno, C. K., **The effect of fines on liquefaction of sands,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/38, 1977, 381-385.

A laboratory investigation was carried out to study the effect of fine grains on the liquefaction potential of isotropically consolidated Ottawa sands under cyclic triaxial loading. All specimens were statically compacted to a dry density of 1.70 g/cm^3. The proportions of fine grains were varied from specimen to specimen. By establishing the dry density of all specimens, the void ratio of the "sand structure" of a specimen varied with the amount of fine grains. The results show that, for a given void ratio of a sand structure where sand to sand contact is possible, the presence of fine grains in the voids increases the resistance to liquefaction under cyclic loading.

● **5.6-17** Pender, M. J., **Modelling soil behaviour under cyclic loading,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/28, 1977, 325-331.

A comprehensive model has been developed to describe the stress-strain behavior of overconsolidated soil. This paper concerns the extension of the model to cover the response of a soil to small-strain cyclic loading. The model continues to be based on the critical state theory of soil behavior and the idea that a constitutive relation for a work-hardening plastic material is appropriate for the calculation of the nonrecoverable strains. Objectives in the development of the model are (1) that the number of parameters needed to characterize a particular soil be minimized and (2) that values for these parameters be obtainable from routine tests. It is concluded that the variation of the apparent shear modulus and equivalent viscous damping ratio with cyclic strain amplitude can be represented most effectively. The model requires five parameters to characterize a material.

● **5.6-18** Ogawa, S., Shibayama, T. and Yamaguchi, H., **Dynamic strength of saturated cohesive soil,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/26, 1977, 317-320.

Cyclic loading tests were conducted by means of a triaxial apparatus to determine the dynamic strength of a saturated cohesive soil. Particular attention was given to the effects of the confining stresses and overconsolidation. The dynamic behavior of the cohesive soil under cyclic loading was similar to that of dense sand. The relationships between the stress ratio and the number of stress cycles were uniquely related in spite of the differing magnitudes of the confining stress. The effects of overconsolidation on the dynamic strength disappeared with an increase in the number of stress cycles at yield, while the pore water pressures continued to increase even after the application of cyclic stress had ceased. The Cu/P (shearing strength/consolidation pressure) obtained from the yield condition was much less than that obtained from the static compression tests.

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● **5.6-19** Hara, A. and Kiyota, Y., **Dynamic shear tests of soils for seismic analyses,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/13, 1977, 247–250.

A Kjellman-type dynamic simple shear apparatus, developed by the authors, is described and used to test clay, sand, and mudstone samples. It is shown that the results of in-situ tests and the results of the shear tests were identical for the most part. The shear moduli, the damping strain-dependencies, and the frequency-dependencies are shown for the three soils tested. Also shown are hysteresis curves for typical samples. These curves indicate that the stress-strain relationships of soils are simpler than previously thought.

● **5.6-20** Ishihara, K. *et al.*, **Liquefaction of anisotropically consolidated sand,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/16, 1977, 261–264.

To evaluate the effects of initial stress conditions on the liquefaction of sand, a series of cyclic triaxial torsion shear tests were conducted on saturated specimens consolidated anisotropically with K_0-values ranging from 0.5 to 1.5. It was found that specimens having a K_0-value less than unity exhibited a smaller resistance to liquefaction than specimens consolidated isotropically. Conversely, a greater resistance occurred in the specimens consolidated with a K_0-value larger than unity.

● **5.6-21** Kobayashi, H. and Nagatsuka, M., **Experimental study on the liquefaction of sandy seabed under offshore oil storage tanks,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. III, OTC 3258, 1978, 1779–1788.

The liquefaction potential of the seabed and the seismic stability of overlying structures is examined using a model of a gravity-type offshore oil storage tank. The influence on the liquefaction potential caused by the presence of a structure and the sea water are discussed.

● **5.6-22** Ishihara, K. and Okada, S., **Effects of stress history on cyclic behavior of sand,** *Soils and Foundations,* 18, *4,* Dec. 1978, 31–45.

To investigate the possible effects of preshearing on the cyclic behavior of saturated sand, two series of cyclic static triaxial tests were performed. In the first series of tests, saturated samples were first subjected to small cyclic stresses having equal amplitudes on both sides of triaxial compression and extension until the pore water pressures increased to values less than the initial effective confining stress. The excess pore water pressures were then allowed to dissipate under the initial confining stress. This part of the stress changes represents the application of stress history to the sample. The samples were further subjected to cyclic stresses in order to observe the pore water pressure and shear strain behaviors as influenced by the previous stress cycle. It was found that the samples subjected to small preshearing developed less pore water pressures and shear strains on both sides of triaxial compression and extension. The second series of the tests was identical to the first series except for the application of a large shear stress to the sample on either side of triaxial compression or extension during the preshearing. It was discovered that the sample subjected to large preshear on one side of triaxial loading, compression or extension, became stiffer on that side, but softer on the opposite side.

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6. Dynamics of Structures

6.1 General

● **6.1-1** Gupta, A. K., **Combination of dynamic loads,** *Probabilistic Analysis and Design of Nuclear Power Plant Structures,* 87–95. (For a full bibliographic citation, see Abstract No. 1.2-17.)

Various methods of combining responses to dynamic loads have been reviewed. The square root of the sum of squares (SRSS) method (a zero-mean process) is used to combine responses to three-component earthquake motions. The conditional probability that the response will be exceeded combined by the SRSS method for the stationary ergodic process is 50% which is approximately applicable to the three components of an earthquake. A modified form of SRSS can be used for processes with nonzero means. More research is needed to determine the appropriate values of the mean responses to individual loads, which, in most practical cases, are nonergodic and a function of initial time and the assumed duration. In conjunction with the cumulative distribution function (CDF) approach, it is suggested that a 50% conditional probability is consistent with existing practice which can be independent of the reliability considerations. However, CDF is a strong function of the probability density function of the phase time which, at present, is not well defined. In the interim, it is suggested that the possibility of using a load factor which can be logically justified be investigated.

● **6.1-2** Boresi, A. P. *et al.*, **Advanced mechanics of materials,** 3rd ed., John Wiley and Sons, New York, 1978, 696.

This book treats the following subject areas: (1) theories of stress and strain; (2) stress-strain-temperature relations; (3) failure criteria; (4) application of energy methods: elastic deflections and statically indeterminate members and structures; (5) torsion; (6) unsymmetrical bending of straight beams; (7) shear center for thin-wall beam cross sections; (8) curved beams; (9) beams on elastic foundations; (10) flat plates; (11) thick-wall cylinders; (12) basic concepts of stress concentrations; (13) applications of effective stress concentration factors; (14) contact stresses; and (15) buckling, or structural instability. An appendix discusses the second moment (moment of inertia) of a plane area. An index is included.

6.2 Dynamic Properties of Materials and Structural Components

6.2-1 Filipich, C. *et al.*, **Vibrations of rectangular, stepped thickness plates with edges elastically restrained against rotation,** *International Journal of Mechanical Sciences,* **20,** 3, 1978, 149–158.

The title problem is solved using simple polynomial coordinate functions which identically satisfy the boundary conditions. The Rayleigh-Ritz method is used to evaluate the natural frequencies. Numerical results are presented for several values of the parameter length to width ratio and a particular type of thickness variation. It is shown that the approximate approach presented is valid for a large combination of boundary conditions.

6.2-2 Radhakrishnan, V. M., **Cumulative damage in low-cycle fatigue,** *Experimental Mechanics,* **18,** 8, Aug. 1978, 292–296.

Cyclic deformation behavior of low-carbon steel and copper under constant-stress amplitude and in a two-step stress change is considered in the intermediate life range. Under constant-stress amplitude, there is initial softening followed by hardening in low-carbon steel. In the case of copper, hardening sets in from the initial stages of stress application. The total hysteretic energy absorbed is not a

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material constant, but depends on the applied stress. The strain-hardening/strain-softening behavior under the second stress level is different from that of the standard fatigue tests and is dependent on the first stress level. An energy-based analysis has been found to predict fairly well the cumulative damage life in low-cycle fatigue.

● 6.2-3 Prathap, G. and Pandalai, K. A. V., **The role of median surface curvature in large amplitude flexural vibrations of thin shells,** *Journal of Sound and Vibration,* **60,** *1,* Sept. 8, 1978, 119–131.

General conclusions regarding the nonlinear vibration of structural components such as curved beams, rings, and thin shells are derived from the study of two examples, the circular ring and the shallow spherical shell. It is shown that, whereas the nonlinear behavior of flat plates and straight bars is generally of a hardening type, the behavior of thin structural elements that have a finite curvature of the undeformed median surface in one or both principal axis directions may be of the hardening or softening type, depending on the structural parameters as well as on whether the shell is open or closed. It is seen that, with careful judgement in the use of mode shapes of one or more terms, the resulting modal equations help one to better appreciate the physics of the problem, whereas sophisticated mathematical models tend to obscure this.

● 6.2-4 Mukhopadhyay, M., **A semi-analytic solution for free vibration of rectangular plates,** *Journal of Sound and Vibration,* **60,** *1,* Sept. 8, 1978, 71–85.

By substituting the basic function which satisfies boundary conditions along two opposite edges in one direction of the plate and then using a suitable transformation, the free vibration equation of the shape function of the plate is reduced to an ordinary differential equation. The resulting equation is expressed in finite difference form. The problem is thus transformed into an eigenvalue problem which on solution yields the natural frequencies of free vibration of plates. Examples have been presented for a variety of plates having different boundary conditions and having constant and variable thickness, and excellent accuracy has been obtained.

● 6.2-5 Peterson, M. R. and Boyd, D. E., **Free vibrations of circular cylinders with longitudinal, interior partitions,** *Journal of Sound and Vibration,* **60,** *1,* Sept. 8, 1978, 45–62.

A method for the analysis of the free vibrations of a circular cylindrical shell with a longitudinal interior plate is developed. This method is based on the extended Rayleigh-Ritz technique. Separate displacement functions are assumed for the shell and plate. Constraint equations are used to enforce displacement compatibility between the plate and shell. The importance of including the in-plane degrees-of-freedom of the plate in the analysis is investigated. Studies are made to determine the effects of the location of the plate and rigid and hinged joints between the plate and shell on the system frequencies and modes. In general, the effect of the joint condition and plate location on the frequencies varies for different modes. The fundamental mode of the partitioned shell predominantly involves bending of the plate unless the plate is very thick. The effect of the joint condition on the frequency depends on the character of the mode, although the frequencies are higher when the joint is rigid than when it is hinged. The fundamental frequency increases as the plate is located farther from the center of the shell, but higher frequencies show a less predictable behavior.

● 6.2-6 Banerjee, M. M., **On the analysis of large amplitude vibrations of non-uniform rectangular plates,** *Journal of Sound and Vibration,* **58,** *4,* June 22, 1978, 545–553.

An analysis of the large amplitude vibrations of non-uniform rectangular plates is presented. The method is based on Berger's idea of neglecting the second invariant of the middle surface strain in the expression corresponding to the total potential energy of the system, in conjunction with a Galerkin procedure.

● 6.2-7 Gupta, U. S. and Lal, R., **Buckling and vibrations of circular plates of variable thickness,** *Journal of Sound and Vibration,* **58,** *4,* June 22, 1978, 501–507.

Axisymmetric vibrations of a circular plate of linearly varying thickness under the action of a hydrostatic in-plane force and resting on a Winkler-type elastic foundation are discussed. The discussion is based on the classical theory of plates. The fourth-order linear differential equation governing the transverse motion is solved by Frobenius' method. Frequency parameters of clamped as well as simply supported plates for the first three modes of vibration are computed for various values of the taper parameter, the foundation modulus, and the in-plane force. Transverse displacements and moments are also computed.

● 6.2-8 Altman, W. and Bismarck-Nasr, M. N., **Vibration of thin cylindrical shells based on a mixed finite element formulation,** *Computers & Structures,* **8,** 2, Apr. 1978, 217–221.

A Hellinger-Reissner functional for thin circular cylindrical shells is presented. A mixed finite element formulation is developed from this functional, which is free from line integrals and relaxed continuity terms. This element is applied to the problem of vibration of rectangular cylindrical shells. Bilinear trial functions are used for all field variables. The element satisfies the compatibility and completeness requirements. The numerical results obtained in

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this work show that convergence is quite rapid and monotonic for a much smaller number of degrees-of-freedom than with other finite element formulations.

● 6.2-9 Prathap, G. and Varadan, T. K., **Large amplitude flexural vibration of stiffened plates,** *Journal of Sound and Vibration,* **57,** *4,* Apr. 22, 1978, 583–593.

The large amplitude free flexural vibration of thin, elastic orthotropic stiffened plates is studied. The boundary conditions considered are either simply supported on all edges or clamped on all edges, and the in-plane edge conditions are either immovable or movable. The governing dynamic equations are derived in terms of nondimensional parameters describing the stiffening achieved, and the solutions are obtained on the basis of an assumed one-term vibration mode shape for various stiffener combinations. In all cases, the nonlinearity is found to be of the hardening type, i.e., the period of nonlinear vibration decreases with increasing amplitude. Some interesting conclusions are drawn about the effect of the stiffening parameters on the nonlinear behavior. A simple method of predicting the postbuckling and static large deflection behavior from the results obtained in this analysis is included.

● 6.2-10 Gorman, D. J., **Free vibration analysis of the completely free rectangular plate by the method of superposition,** *Journal of Sound and Vibration,* **57,** *3,* Apr. 8, 1978, 437–447.

While the subject of free vibration analysis of a completely free rectangular plate has a history which goes back nearly two centuries, it remains a fact that most theoretical solutions to this classical problem are considered to be, at best, approximate in nature. This is because of the difficulties encountered in trying to obtain solutions which satisfy the free edge conditions as well as the governing differential equation. In a new approach to this problem, using the method of superposition, solutions which satisfy identically the differential equation and which satisfy the boundary conditions with any desired degree of accuracy are obtained. Eigenvalues of four digit accuracy are provided for a wide range of plate aspect ratios and modal shapes. Exact delineation is made between the three families of modes which are characteristic of this plate vibration problem. Accurate modal shapes are provided for the response of completely free square plates.

● 6.2-11 Sridhar, S., Mook, D. T. and Nayfeh, A. H., **Nonlinear resonances in the forced responses of plates, part II: asymmetric responses of circular plates,** *Journal of Sound and Vibration,* **59,** *2,* July 22, 1978, 159–170.

The dynamic analog of the von Karman equations is used to study the forced response, including asymmetric vibrations and traveling waves, of a clamped circular plate subjected to harmonic excitations with frequencies near one of the natural frequencies. The method of multiple scales, a perturbation technique, is used to solve the nonlinear governing equations. The approach provides insight into the nature of the nonlinear forced resonant response. It is shown that in the absence of internal resonance (i.e., a combination of commensurable natural frequencies) or when the frequency of excitation is near one of the lower frequencies involved in the internal resonance, the steady state response can only have the form of a standing wave. However, when the frequency of excitation is near the highest frequency involved in the internal resonance, it is possible for a traveling wave component of the highest mode to appear in the steady state response.

● 6.2-12 Levinson, M. and El Menoufy, M., **Free vibrations of skirt supported pressure vessels—an engineering application of Timoshenko beam theory,** *Journal of Sound and Vibration,* **57,** *3,* Apr. 8, 1978, 413–424.

Timoshenko beam theory is applied to the study of the free vibrations of skirt-supported pressure vessels in this paper. Such systems are used in the process and power generation industries as well as aboard nuclear powered vessels. It is shown that the analysis is not significantly more complicated than the analysis of skirt-vessel combinations by Euler-Bernoulli beam theory. This latter analysis is provided in an appendix. Two sets of boundary conditions are considered; namely, the cases of (a) a cantilevered system and (b) a fixed-pinned system. The first two natural frequencies of nine typical cases are calculated and compared with the corresponding results obtained from Euler-Bernoulli beam theory. The numerical differences are significant so that if a beam theory is adequate to model the system, it is clear that Timoshenko beam theory is the appropriate one to use. In addition, the first two mode shapes for a particular case are presented for comparison with the corresponding mode shapes predicted by Euler-Bernoulli beam theory. Finally, some comments on the modeling and analysis of specific, real systems are made. It is emphasized that the purpose of the paper is to demonstrate that Timoshenko beam theory is not unduly difficult to apply to problems of engineering interest when a beam theory model is suitable.

● 6.2-13 Chonan, S., **Random vibration of an elastically supported circular plate with an elastically restrained edge and an initial tension,** *Journal of Sound and Vibration,* **58,** *3,* June 8, 1978, 443–454.

This paper considers the problem of the random vibration of an elastically supported circular plate with an elastically restrained edge and an initial radial tension. The random excitation is taken to be a distribution of spatially uncorrelated random forces. Analytical expressions for the mean square displacement and moment are derived by using the orthogonality property of the mode functions.

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Numerical results are then given for a range of parameters. The main result is that, in general, the mean square displacement of the plate takes on a maximum value at the center of the plate, while the mean square moment also takes on a maximum value at the center of the plate or along the edge of the plate, depending upon the relative values of the elastic edge constraint, the initial radial tension, and the stiffness of the foundation.

● 6.2-14 Dokumaci, E., **Pseudo-coupled bending-torsion vibrations of beams under lateral parametric excitation,** *Journal of Sound and Vibration,* 58, 2, May 22, 1978, 233–238.

This paper presents a theoretical and experimental study of the dynamic stability of straight uniform beams under lateral parametric excitation. The calculation of the boundaries of stability is based on the finitization of the problem by the Rayleigh-Ritz method and application of the small parameter stability criterion to the resulting periodic linear system. An experimental study was carried out on a cantilever beam excited by base motion acting in the largest plane of rigidity of the beam. A close correlation was established between the calculated and measured boundaries of instability by taking into account the nonlinear damping characteristics exhibited by the beams tested.

● 6.2-15 Grant, D. A., **The effect of rotary inertia and shear deformation on the frequency and normal mode equations of uniform beams carrying a concentrated mass,** *Journal of Sound and Vibration,* 57, *3,* Apr. 8, 1978, 357–365.

New frequency equations for transverse vibrations of Timoshenko beams carrying a concentrated mass at an arbitrary point along the beam are given. Normal mode equations for the hinged-hinged beam are given and the orthogonality condition is presented for beams with hinged, clamped, or free ends. A numerical example is given, and frequency charts show the effects of varying the size and location of the concentrated mass.

● 6.2-16 Laura, P. A. A., Luisoni, L. E. and Ficcadenti, G., **On the effect of different edge flexibility coefficients on transverse vibrations of thin, rectangular plates,** *Journal of Sound and Vibration,* 57, *3,* Apr. 8, 1978, 333–340.

To solve problems of transverse vibration of thin rectangular plates with different edge flexibility coefficients, polynomial coordinate functions are used which identically satisfy the boundary conditions. It is shown that by a proper combination of the polynomials several modes of vibrations can be analyzed with a minimum amount of labor. A variational formulation is used to generate the frequency equation. Eigenvalues calculated by using a two-term approximation seem to possess extremely good accuracy, at least from an engineering viewpoint. It is also shown that the effect of in-plane forces or the case when the plate is supported on a Winkler-type foundation can be studied without any formal difficulties.

● 6.2-17 Bassily, S. F. and Dickinson, S. M., **Buckling and vibration of in-plane loaded plates treated by a unified Ritz approach,** *Journal of Sound and Vibration,* 59, *1,* July 8, 1978, 1–14.

The problem of the buckling and lateral vibration of rectangular plates subject to in-plane loads is treated by using a Ritz approach for the determination of the middle surface stresses caused by the in-plane loading and the analysis of the consequent out-of-plane buckling and vibrational characteristics of the plates. Since the stress function formulation of the middle surface stress problem is formally analogous to the plate bending problem, the same type of admissible functions—ordinary and degenerated beam vibration mode shapes—are employed in the Ritz series for both parts of the problem. The approach permits the accurate treatment of plates subject to real in-plane loads when the middle surface stresses may not be realistically representable by simple polynomials, as has been assumed in earlier studies. Several numerical examples are presented, illustrating the applicability of the approach and giving an indication of the order of errors that may result in the determination of the out-of-plane characteristics of plates when using simplifying assumptions for the in-plane stress field.

● 6.2-18 Wasserman, Y., **Spatial symmetrical vibrations and stability of circular arches with flexibly supported ends,** *Journal of Sound and Vibration,* 59, *2,* July 22, 1978, 181–194.

In this work, exact formulae are given for determining the lowest natural frequencies and critical loads of elastic circular arches with flexibly supported ends for symmetrical vibration in the direction perpendicular to the initial curvature of the arch. This investigation is concerned with three cases of load behavior during the process of deformation. The values of the frequencies and critical loads are shown to be dependent on the opening angle of the arch, the stiffness of the flexibly supported ends, and the ratio of the flexural rigidity to the torsional rigidity of the arch cross section.

● 6.2-19 Prathap, G. and Varadan, T. K., **On the nonlinear vibrations of rectangular plates,** *Journal of Sound and Vibration,* 56, *4,* Feb. 22, 1978, 521–530.

A solution, based on a one-term mode shape, for the large amplitude vibrations of a rectangular orthotropic plate, simply supported on all edges or clamped on all edges for movable and immovable in-plane conditions, is found by using an averaging technique that helps to satisfy the in-plane boundary conditions. This averaging technique

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for satisfying the immovable in-plane conditions can be used to resolve many anisotropic and skew plate problems for which, when a stress function is used, the integration of the u and v equations is difficult, if not impossible. The results obtained by this technique are compared with those in the literature for the isotropic case, and excellent agreement is found. Results available for the one-term mode shape solutions of these problems are compared, and the nonlinear effect is presented as functions of aspect ratio and of the orthotropic elastic constants of the plate. The results are further compared with those based on the Berger method. The detailed comparative studies show that the use of the Berger approximation for large deflection static and dynamic problems and its extension to anisotropic plates, skew plates, etc., can lead to quite inaccurate results.

● **6.2-20** Eastep, F. E. and Hemmig, F. G., **Estimation of fundamental frequency of non-circular plates with free, circular cutouts,** *Journal of Sound and Vibration,* **56,** *2,* Jan. 22, 1978, 155–165.

A method of obtaining approximate fundamental frequencies of slightly noncircular plates with free circular cutouts is developed. An approximate expression for the radius of each bounding curve is written as a truncated Fourier series. The support conditions, which are written in terms of a perturbation series of the modes of a circular annulus, are satisfied on the approximate boundaries. The approximate characteristic equation (either first- or second-order approximations) is obtained from satisfaction of the support conditions and the fundamental frequency determined as the first root to this characteristic equation. Approximate frequencies of the fundamental mode of a clamped elliptical plate, a square plate with a circular cutout, and an eccentric annulus are determined to demonstrate the second-order approximation. In addition, the first-order approximation to the fundamental mode of an eccentric annulus is obtained.

● **6.2-21** Vijayakumar, K. and Ramaiah, G. K., **Analysis of vibration of clamped square plates by the Rayleigh-Ritz method with asymptotic solutions from a modified Bolotin method,** *Journal of Sound and Vibration,* **56,** *1,* Jan. 8, 1978, 127–135.

Estimates of flexural frequencies of clamped square plates are obtained by the modified Bolotin method. The mode shapes in "each direction" are then determined and the product functions of these mode shapes are used as admissible functions in the Rayleigh-Ritz method. The data for the first 20 eigenvalues in each of the three (four) symmetric groups obtained by the (1) Bolotin, (2) Rayleigh and (3) Rayleigh-Ritz methods are reported here. The Rayleigh estimates are found to be much closer to the true eigenvalues than the Bolotin estimates. The present product functions are found to be much superior to the conventional beam eigenmodes as admissible functions in the Rayleigh-Ritz method of analysis.

● **6.2-22** Bailey, C. D., **Direct analytical solutions to nonuniform beam problems,** *Journal of Sound and Vibration,* **56,** *4,* Feb. 22, 1978, 501–507.

The direct analytical solution to the vibration of nonuniform beams with and without discontinuities and with various boundary conditions is presented. Results are compared to results from the exact solution for certain cases where the exact solution has been obtained. It is shown that the direct solution converges to the exact solution with "indefinite accuracy," as Hamilton suggested.

● **6.2-23** Wang, T. M. and Gagnon, L. W., **Vibrations of continuous Timoshenko beams on Winkler-Pasternak foundations,** *Journal of Sound and Vibration,* **59,** *2,* July 22, 1978, 211–220.

A dynamic analysis of continuous Timoshenko beams on Winkler-Pasternak foundations by means of general dynamic slope-deflection equations is presented. A three-span continuous beam on a Winkler-Pasternak foundation subjected to free and forced vibrations is used to illustrate the application of the proposed method and to show the effects of rotary inertia, transverse-shear deformation, and foundation constants on the beam.

● **6.2-24** Ibrahim, I. M. and Farah, A., **Enhancing the damping of slabs by viscoelastic layers,** *Journal of the Structural Division, ASCE,* **104,** *ST5,* Proc. Paper 13766, May 1978, 817–827.

The potential of constrained viscoelastic layers for enhancing the damping of two-way slab floor systems with simply supported and clamped boundary conditions subjected to dynamic loading is examined. The finite strip method is extended to the analysis of the resulting sandwich structures. The damping of the sandwich system is mainly a result of the shear deformation of the viscoelastic layers; it is described by a composite loss factor. The results demonstrate the effect of the elastic, damping, and geometric properties of the attached layers and their location in the domain of the slab on the damping of the structures considered. It is pointed out that substantial damping can be achieved by the proper choice of these parameters.

● **6.2-25** Plunkett, R. and Sax, M., **Nonlinear material damping for nonsinusoidal strain,** *AEM-P1-78,* Dept. of Aerospace Engineering and Mechanics, Univ. of Minnesota, Minneapolis, July 1978, 11.

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The damping in uniform and nonuniform cantilever beams was measured at resonance for a range of amplitudes of simultaneous steady-state first- and second-mode vibration. For two linear materials, aluminum and cross-ply fiberglass, the damping factor in each mode is independent of amplitude and is unaffected by the presence of the other mode. For a fully annealed tool steel with highly nonlinear damping, the damping factor in each mode is markedly increased by the presence of the other mode.

● 6.2-26 Vanderbilt, M. D., **Fixed end action and stiffness matrices for nonprismatic beams,** *Journal of the American Concrete Institute,* **75**, *7*, Title No. 75-31, July 1978, 290–298.

An algorithm is described which may be used to compute the fixed end action and stiffness matrices for nonprismatic beams subject to point and distributed loads. The program may be used as a subroutine in a structural analysis program or as a complete program for use with a manually performed moment distribution analysis.

● 6.2-27 Diez, L., Gianetti, C. E. and Laura, P. A. A., **A note on transverse vibrations of rectangular plates subject to in-plane normal and shear forces,** *Journal of Sound and Vibration,* **59**, *4*, Aug. 22, 1978, 503–509.

To determine the fundamental frequency of the transverse vibration of rectangular plates with edges elastically restrained against rotation and subjected to uniformly distributed in-plane normal and shear stresses, the plate displacement function is first expressed in terms of polynomial coordinate functions which identically satisfy the boundary conditions. A frequency equation is then generated by using a variational formulation. Numerical results for both the fundamental mode and the first fully antisymmetrical mode are given.

● 6.2-28 Orudgev, F. M. *et al.*, **The influence of non-elastic properties of the reinforced concrete on the performance of the frame constructions under seismic loads,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-41, 1978, 305–310.

An investigation of the rigidity parameters of reinforced concrete frame constructions is examined, taking into account the non-elastic properties of reinforced concrete. Suggestions for estimating the values of the residual deformation are given to determine the energy absorption coefficient value. The results of the investigation of the variation in character of the energy absorption coefficient value with an increase in the loading level and cycle number are described.

● 6.2-29 Marangoni, R. D., Cook, L. M. and Basavanhally, N., **Upper and lower bounds to the natural frequencies of vibration of clamped rectangular orthotropic plates,** *International Journal of Solids and Structures,* **14**, *8*, 1978, 611–623.

The Rayleigh-Ritz technique, using clamped beam eigenfunctions, has been employed to determine the upper bounds for the eigenvalues of a clamped orthotropic plate. The decomposition technique, after Bazely and Fox, has been used to estimate the lower bounds for the first few natural frequencies. The estimates for the upper bounds have been evaluated for all modes by not imposing any restriction on the symmetry conditions. Variations of the first two natural frequencies for various rigidity and aspect ratios, which can be of some use to designers, are presented. Also, the upper and lower bounds for the first few natural frequencies are tabulated. The results for special cases are compared with other reported data whenever such results are available.

● 6.2-30 Ueng, C. E. S. and Nickels, Jr., R. C., **Dynamic response of a structural panel by Bolotin's method,** *International Journal of Solids and Structures,* **14**, *7*, 1978, 571–578.

Bolotin's asymptotic method is adopted to investigate the dynamic response of a rectangular structural panel with elastic edge constraints resembling a box structure. Experimental determination of the frequency response is also included for comparison purposes. The method is proven to be extremely versatile for solving a broad class of the aforementioned problems.

● 6.2-31 Niyogi, B. K. and Sethi, J. S., **Simplified seismic analysis method for small pipes,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-72, 1978, 541–548.

It is economical to perform seismic analyses of small pipes and pipes belonging to low-safety classes by simplified methods. Spacing of the seismic restraints needs to be based upon stress, deflection, and frequency criteria. The ideal analysis would be one that satisfies the three criteria. This paper outlines a procedure which is simple to use and, at the same time, very general.

● 6.2-32 Galbov, S., **Some approaches for definition of elastic and other parameters of a material as dependent upon the ratio of elastic wave propagation velocities,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-06, 1978, 45–52.

● 6.2-33 Sonoda, K., Kobayashi, H. and Ishio, T., **Circular plates on linear viscoelastic foundations,** *Journal of the Engineering Mechanics Division, ASCE,* **104**, *EM4*, Proc. Paper 13945, Aug. 1978, 819–828.

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Solutions are presented for the quasistatic bending problem of circular plates on linear viscoelastic foundations under arbitrary loading conditions. The solutions are developed using the eigenfunctions found in the free lateral vibrations of circular plates with the same geometry and boundary conditions. The correspondence principle between a linear elastic boundary value problem and a viscoelastic problem is used. Results of numerical calculations for the variations in deflection and reactive force in space and time are illustrated for the viscoelastic foundations of Kelvin (Voigt) and Maxwell, and for standard linear solid types.

6.2-34 Gorman, D. J., **Free vibration analysis of rectangular plates with inelastic lateral support on the diagonals,** *The Journal of the Acoustical Society of America,* **64,** *3,* Sept. 1978, 823-826.

An analytical solution is obtained for the problem of the free vibration of a rectangular plate with simple support at the edges and inelastic lateral support along one diagonal. The solution of the double sine series type introduced by Navier can readily be extended to plates with similar support on both diagonals and different kinds of edge support.

● 6.2-35 Keong, Y. S., **Prestressed concrete beam-column joints,** *78/2,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1978, 81.

Results are presented from tests of three beam-column assemblies under static cyclic loading. The beams were of prestressed concrete and the columns of reinforced concrete. It is concluded that vertical shear reinforcement in the bending plane of the joint core, in the form of intermediate column bars with horizontal ties, enables the joint core shear force to be transferred effectively.

● 6.2-36 Bradford, L. G. and Dong, S. B., **Natural vibrations of orthotropic cylinders under initial stress,** *Journal of Sound and Vibration,* **60,** *2,* Sept. 22, 1978, 157-175.

A finite element method is presented for the analysis of the vibratory characteristics of laminated orthotropic cylinders. The cylinder may have an arbitrary number of bonded elastic orthotropic cylindrical laminates, each with distinct thickness, density, and mechanical properties. The formulation is capable of treating a three-dimensional initial stress state which is radially symmetric. Biot's incremental deformation theory is the basis for this study. A homogeneous, isotropic cylinder was analyzed and these numerical results were in excellent agreement with those from an exact analysis. Additional examples of two geometries of a three-layer composite and a sandwich cylinder are given to further illustrate the influence of the initial stress on the physical behavior of such structures.

● 6.2-37 Chia, C. Y. and Prabhakara, M. K., **A general mode approach to nonlinear flexural vibrations of laminated rectangular plates,** *Journal of Applied Mechanics, ASME,* **45,** *3,* Sept. 1978, 623-628.

This paper describes an analytical investigation of free, flexural, large amplitude vibrations of rectangular composite plates. Solutions of the dynamic von Karman-type equations of these plates in conjunction with different boundary conditions are obtained by use of a generalized double Fourier series and the method of harmonic balance. Numerical calculations for multimode vibrations of unsymmetric cross-ply and angle-ply plates having various material properties and lamination geometry were performed for clamped and simply supported stress-free edges. The results indicate that the effect of modal vibration coupling on nonlinear frequencies is not appreciably significant for isotropic plates but the effect is considerably significant for composite plates, especially for clamped high-modulus laminates.

● 6.2-38 Chang, C. H., **Membrane vibrations of conical shells,** *Journal of Sound and Vibration,* **60,** *3,* Oct. 8, 1978, 335-343.

Exact solutions for membrane vibrations of conical shells resulting from forces acting in the meridional direction are obtained. Frequency equations for the free vibration of conical shells with various end conditions but free from the in-plane shearing force are presented. Also presented are the asymptotic expressions, numerical results of frequency spectra, and some typical normal modes. The formal solutions for the transient and forced vibrations of such cones are given.

● 6.2-39 Trompette, P., Boillot, D. and Ravanel, M.-A., **The effect of boundary conditions on the vibration of a viscoelastically damped cantilever beam,** *Journal of Sound and Vibration,* **60,** *3,* Oct. 8, 1978, 345-350.

The dynamic behavior of a three-layered cantilever beam damped by a viscoelastic core is studied. Two selected boundary conditions are compared. One of the conditions requires the omission of the hypothesis used by several authors that the ratio of the longitudinal displacements in the elastic parts of the beam is constant. A finite element analysis and supporting experimental results indicate that the omission of this hypothesis may influence significantly the estimated value of the fundamental frequency.

● 6.2-40 Venkatesan, S. and Kunukkasseril, V. X., **Free vibration of layered circular plates,** *Journal of Sound and Vibration,* **60,** *4,* Oct. 22, 1978, 511-534.

Free vibrational characteristics of layered circular plates are considered. Each layer is isotropic and, in general, the layers are assumed to have different material properties and thicknesses. Equations incorporating shear deformation and rotatory inertia are developed for asymmetric motion. For axisymmetric motion exact closed-form solutions are obtained. For plates with layers having equivalent Poisson ratios, it is shown that the solution for the asymmetric modes can be obtained in terms of Bessel functions. Numerical results for various layer arrangements and boundary conditions are obtained for axisymmetric modes. Experiments were conducted on carefully prepared models of two-layered annular and complete plates. The mode shapes and corresponding frequencies are tabulated. The axisymmetric results are compared with the theoretical values.

● **6.2-41** Jacquot, R. G., **Optimal dynamic vibration absorbers for general beam systems,** *Journal of Sound and Vibration,* **60,** *4,* Oct. 22, 1978, 535–542.

A technique is developed to determine the optimal dynamic vibration absorber parameters for the elimination of excessive vibration in sinusoidally forced Bernoulli-Euler beams. The result is presented in a general form in order to include all possible sets of ordinary boundary conditions and absorber attachment points. This is done by employing a single mode expansion for the beam in an assumed mode approach. The general equations developed are applied to a point-forced cantilever beam with a viscously damped dynamic absorber attached at the beam midpoint. The optimal values developed for the single mode approximation are evaluated with account taken of the first five beam modes where discrepancies are noted near the higher order beam resonances that are shifted slightly as a result of the presence of the absorber.

● **6.2-42** Sathyamoorthy, M., **Vibration of skew plates at large amplitudes including shear and rotatory inertia effects,** *International Journal of Solids and Structures,* **14,** *10,* 1978, 869–880.

An approach for analysis of the large amplitude, free, undamped flexural vibration of elastic, isotropic skew plates is developed using Hamilton's principle. The effects of transverse shear and rotatory inertia are considered. Assuming a vibration mode of the product form, the relationship between amplitude and period is studied for clamped plates of varying aspect ratios and skew angles. The time differential equation, i.e., the modal equation when numerically integrated, provides information about the effects of transverse shear and rotatory inertia on aspect ratios and skew angles of thin and moderately thick plates at small and at large amplitudes.

● **6.2-43** Nagaya, K., **Dynamics of viscoelastic plate with curved boundaries of arbitrary shape,** *Journal of Applied Mechanics, ASME,* **45,** *3,* Sept. 1978, 629–635.

This paper is concerned with vibration and transient response problems of viscoelastic plates with curved boundaries of arbitrary shape subjected to general dynamic loads. The results for free and forced vibration problems are given in generalized forms for arbitrarily shaped plates. As examples of this problem, the free vibration of a circular clamped viscoelastic plate with an eccentric hole and the dynamic response of a circular solid viscoelastic plate subjected to an eccentric annular impact load are discussed. Numerical results are calculated for both problems and compared with experimental results.

● **6.2-44** Ovunc, B., **In-plane vibration of plates by continuous mass matrix method,** *Computers & Structures,* **8,** *6,* June 1978, 723–731.

The continuous mass matrix method derived for frameworks is extended to the analysis of the in-plane vibration of plates. A continuous mass distribution which is equivalent to the actual mass distribution of a plate is considered for each rectangular finite element. Taking into account that the rigid body movement produces inertial forces in dynamic analysis for a rectangular plate element, eight independent conditions are provided to satisfy eight independent freedoms. Each condition is obtained from an independent displacement distribution satisfying the equations of motion at any point of the element and not only at the nodes of the rectangle. The dynamic element stiffness matrix thus obtained is a function of the natural circular frequency. The limit of the dynamic element stiffness matrix, when the value of the natural circular frequency tends to zero, is the static, stress-compatible element stiffness matrix. The analysis of plates under forcing forces is performed by modal analysis after the natural circular frequencies and the corresponding modal shapes have been obtained from the free vibrations, since all the forcing forces are assumed to be functions of the same time variation. Otherwise, one must use a numerical analysis. The effects of the sizes, the number of the meshes, the additional static load on the plate, and the rigidity of the boundaries on the vibration of the plate are discussed. A few example problems are solved to illustrate the above-mentioned effects. The numerical results obtained by the continuous mass matrix method are compared with those obtained by the consistent mass matrix method. The convergence in terms of the mesh sizes and the limit of convergence are examined.

● **6.2-45** Raju, K. K., Rao, G. V. and Raju, I. S., **Effect of geometric nonlinearity on the free flexural vibrations of moderately thick rectangular plates,** *Computers & Structures,* **9,** *5,* Nov. 1978, 441–444.

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The effect of geometric nonlinearity on the free flexural vibrations of moderately thick rectangular plates is studied. Finite element formulation is employed to obtain the nonlinear to linear period ratios for some rectangular plates. A conforming finite element of rectangular shape, in which the effects of shear deformation and rotatory inertia are included, is developed and used for the analysis. Results are presented for both simply supported and clamped boundary conditions.

● 6.2-46 Varadan, T. K. and Pandalai, K. A. V., **Nonlinear flexural oscillations of orthotropic shallow spherical shells,** *Computers & Structures,* 9, *4,* Oct. 1978, 417–425.

The effects of curvature and polar orthotropy on the nonlinear dynamic behavior of a shallow spherical shell are investigated. Numerical solutions based on an assumed two-term mode shape for the axisymmetric, forced (uniform pressure), and free vibrations are obtained for different shell geometries and orthotropic material constants. The results, when specialized for isotropic material, are in good agreement with results in the literature. Based on a one-term mode shape solution, the values of the geometric parameter, at which the transition from hardening to softening types of nonlinearity takes place and where the reversal of the softening trend occurs, are obtained for different values of the orthotropic constants.

● 6.2-47 Narayanan, G. V. and Beskos, D. E., **Use of dynamic influence coefficients in forced vibration problems with the aid of fast Fourier transform,** *Computers & Structures,* 9, *2,* Aug. 1978, 145–150.

The use and importance of dynamic stiffness influence coefficients in the flexural forced vibrations of beam structures are described. The dynamic forces can be either harmonic or general transient forces. The dynamic influence coefficients are defined and computed in the Fourier transform plane; these are given in tabular form for a uniform free-free beam. The dynamic problem formulated in terms of these coefficients is reduced to a static form. The dynamic response is obtained, in general, by a matrix inversion in the Fourier transform plane and a numerical inversion based on the Cooley-Tukey algorithm of the transformed solution. Computations of the forced vibrations of a simple beam and a rigid frame illustrate the use of dynamic coefficients and demonstrate their advantages, including accuracy, simplicity of formulation, and speed of computation.

● 6.2-48 Prathap, G. and Varadan, T. K., **The large amplitude vibration of hinged beams,** *Computers & Structures,* 9, *2,* Aug. 1978, 219–222.

The large amplitude free vibrations of a simply supported beam with ends kept a constant distance apart are studied using the actual nonlinear equilibrium equations (i.e., specification of loads in terms of the deformed coordinates of the beam) and the exact nonlinear expression for curvature in addition to the nonlinearity arising from the axial force. A variable separable assumption, together with certain assumptions about the behavior of the time function, defines an eigenvalue characteristic of the vibration. A numerically exact successive integration and iterative technique establishes the dependence of this quantity on the amplitude of vibrations. The hardening effect of nonlinearity is then interpreted in terms of the variation of this quantity with the amplitude of vibration. This new criteria for defining nonlinearity is compared with several other criteria in the literature. The present analysis allows the separation of the effects of stretching and large deflection equations on the nonlinear behavior. The conclusion can be made, based on numerical evidence, that the predominant nonlinearity is caused by stretching. The axial force at any station in the beam and the bending stress also can be computed in a numerically exact sense at the point of maximum amplitude.

● 6.2-49 Pardoen, G. C., **Asymmetric vibration and stability of circular plates,** *Computers & Structures,* 9, *1,* July 1978, 89–95.

The asymmetric vibration and stability of circular and annular plates using the finite element method are discussed. The plate bending model consists of one-dimensional circular and annular ring segments with a Fourier series approach used to model the problem asymmetries. Using displacement functions, which are the exact solutions of the static plate bending equation, the stiffness coefficients corresponding to the first and the nth harmonics are used in closed form. By assuming that the static displacement function closely represents the vibration and stability modes, the mass and stability coefficient matrices for an annular and circular element are also constructed for the first and the nth harmonics. Several numerical examples are presented to demonstrate the efficiency and accuracy of the finite element model compared with that of classical methods.

● 6.2-50 Suzuki, S.-I., **Dynamic behaviour of a beam subjected to a force of time-dependent frequency *(continued)*,** *Journal of Sound and Vibration,* 60, *3,* Oct. 8, 1978, 417–422.

This paper examines in detail the dynamic behavior of a beam when the (radian) frequency of an external force passes through the first critical frequency ω_1 of the beam, increasing or decreasing. The external force is assumed to be proportional to $\sin(at^2/2 + bt^3/3)$ with respect to time, where a and b are constants. Also treated is the case of a beam subjected to constant axial force. 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 maximum values of the dynamic

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deflection are greatly affected by the value of ω_{max}/ω_1 (where ω_{max} is the maximum value of the frequency of the external force) when the forcing frequency passes through ω_1, decreasing.

● **6.2-51** Mazumdar, J. and Bucco, D., **Transverse vibrations of viscoelastic shallow shells,** *Journal of Sound and Vibration,* 57, *3,* Apr. 8, 1978, 323–331.

A method for determining the time history of motion of viscoelastic shallow shells under arbitrary time-dependent transverse load is presented. The method is based upon the concept of iso-amplitude contour lines on the surface of the shell. It is shown that the time behavior can be found by using the frequency of free vibration of the associated elastic shallow shell. As an illustration of the technique, the problem of a shallow dome upon an elliptic base is discussed, and details are explained by graphs.

● **6.2-52** Burroughs, C. B. and Magrab, E. B., **Natural frequencies of prolate spheroidal shells of constant thickness,** *Journal of Sound and Vibration,* 57, *4,* Apr. 22, 1978, 571–581.

General displacement-equilibrium equations, which include the effects of transverse shear and rotary inertia, have been derived for a prolate spheroidal shell of constant thickness subject to a harmonically time-varying, arbitrary, spatially distributed force normal to the shell surface. The approximate solutions for the two nontorsional displacements of the shell middle surface and the nontorsional rotation of the shell cross section are obtained by using Galerkin's variational method. Numerical results are presented for the seven lowest axisymmetric natural frequencies of the shell. When 15 term solutions are used for both thick and thin shells, which have eccentricities that vary from 0.13 to 0.89, the approximate natural frequencies for the first seven flexural modes are all found to converge to within less than 8% of the final values given, with most converging to within less than 2%. Good agreement with other published results is obtained for the approximate natural frequencies of a thin prolate spheroidal shell and for the exact natural frequencies of a thick spherical shell. Additional results are presented for the natural frequencies of moderately thick shells as a function of shell eccentricity, mode number, and shell thickness.

● **6.2-53** Anderson, G. L., **Natural frequencies of two cantilevers joined by a rigid connector at their free ends,** *Journal of Sound and Vibration,* 57, *3,* Apr. 8, 1978, 403–412.

The derivation of the equations of motion is given for a system consisting of two identical parallel cantilevers joined by a rigid connector at their free ends. By using elementary beam theory, it is found that the longitudinal and flexural deformations of the system are coupled through the boundary conditions but not through the differential equations. The associated free vibration problem is solved, and it is shown that the frequency determinant can be factored, yielding two independent frequency equations. One of these corresponds to the pure, free longitudinal motion of a pair of rods connected by a rigid body at their tips (both rods being equally stretched or compressed simultaneously), whereas the second and more complicated is pertinent for the system undergoing flexural deformations in both rods—stretching in one rod and compression in the other. This latter frequency equation is solved numerically, and the variations of the first six natural frequencies with connector thickness and length parameters are displayed graphically. Two orthogonality conditions for the eigenfunctions are derived, and a relatively simple form for the normalizing factor is presented.

● **6.2-54** Shivakumar, K. N. and Krishna Murty, A. V., **A high precision ring element for vibrations of laminated shells,** *Journal of Sound and Vibration,* 58, *3,* June 8, 1978, 311–318.

This paper presents a sixteen degrees-of-freedom ring element for natural vibration analysis of laminated cylindrical or conical shells. The successful performance of this element has been demonstrated by typical numerical studies on cylindrical and conical isotropic and laminated composite shells.

● **6.2-55** Nagai, K. and Yamaki, N., **Dynamic stability of circular cylindrical shells under periodic compressive forces,** *Journal of Sound and Vibration,* 58, *3,* June 8, 1978, 425–441.

The dynamic stability of circular cylindrical shells under both static and periodic compressive forces is theoretically analyzed under four different boundary conditions using the Donnell equations modified with the transverse inertia force. The effect of the axisymmetric unperturbed bending vibration is taken into consideration. The problem is first reduced to that of a finite degree-of-freedom system with the Galerkin procedure, the stability of which is examined using Hsu's method. Calculations are carried out for typical cases, and the instability regions of the principal, secondary, and combination parametric resonances are determined for frequencies up to several times the lowest natural frequency. It is found that the effect of the unperturbed motion is quite significant for shells with moderate length while the effect of the longitudinal resonance is generally negligible for thin shells.

● **6.2-56** Paskaleva, Iv., **Nonelastic deformation in RC frames and their influence on dynamic characteristics,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-19, 1978, 151–157.

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Experimental and theoretical investigations were conducted of the influence of inelastic deformations on the behavior of reinforced concrete frames with infill walls. The frames were subjected to harmonic excitations. H. Kouderer's method was used to determine the natural period of vibrations for the theoretical investigation. The change in the natural period as a function of the inelastic deformations is examined. The experimental and theoretical results are compared, and conclusions are drawn.

● 6.2-57 Bull, I. N., **The shear strength of relocated plastic hinges**, *78/11*, Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1978, 115.

This report describes reversed cyclic load tests conducted on three reinforced concrete beam-column subassemblages. In each case, the critical section of the plastic hinge in the beam was removed from the column face. The shear force in the plastic hinge zone was resisted by a different mechanism in each of the three specimens. In the first beam, the shear reinforcement consisted of conventional vertical beam stirrups which were designed to resist the entire shear force. They also provided lateral support for the longitudinal reinforcement. A significant proportion of the shear force in the plastic hinge zone was resisted by 45° diagonal reinforcement in the second specimen. Vertical stirrups in this region were designed to resist the excess shear force and to provide lateral support for the longitudinal reinforcement. In the final specimen, all forces in the plastic hinge region were resisted by inclined flexural reinforcement. The purpose of the concrete and secondary reinforcement in the plastic hinge region was to provide support for the longitudinal reinforcement and to prevent buckling.

The results show that the danger of pullout of the beam flexural reinforcement from a beam-column joint can be completely eliminated by removing the plastic hinge from the column face. This enables a significant proportion of the joint shear forces to be carried by concrete arch action, which may result in considerable joint shear steel savings. The tests also showed that the use of vertical beam stirrups alone in a plastic hinge region subjected to high shear stresses is questionable. The interaction of flexural and shear cracking in a plastic hinge region results in the formation of a near-vertical crack which may not be crossed by the shear reinforcement. In this case, the only effective resistance to shear force at low loads is by dowel action. In the beam tested, this resulted in a degradation of both strength and stiffness and consequently led to reduced energy dissipation.

Diagonal reinforcement in the plastic hinge zone considerably improved the beam's performance. At low loads, resistance to shear was provided by the diagonal reinforcement and dowel action was minimized, resulting in marked improvement in the hysteretic behavior of the beam and energy dissipation characteristics. The use of inclined flexural reinforcement in the central portion of the span resulted in a good spread of yielding along the beam. High displacement ductilities were obtained without concentration of the post-elastic deformations in a critical region. The beam showed no degradation in strength and had good energy dissipation characteristics.

● 6.2-58 Burdette, E. G. and Bernal, D., **Ductility ratio for slabs**, *Journal of the Structural Division, ASCE*, **104**, *ST11*, Proc. Paper 14131, Nov. 1978, 1741-1748.

An approximate method is presented for calculation of the ultimate deflection of a reinforced concrete slab subjected to a point load at the center. This deflection is divided by the yield deflection to obtain a permissible ductility ratio for the slab. This ratio is useful in the approximate dynamic analyses of slabs subjected to impulse and impact loads. The method takes account of the compressive strength of the concrete, the yield strength of the steel, the ratios of tensile and compressive steel in a cross section of slab, and the slab geometry. The method is suggested as a rational replacement for the empirical equations in current use. Comparisons with test data indicate that the method is reasonable and conservative.

● 6.2-59 Hughes, B. P. and Watson, A. J., **Compressive strength and ultimate strain of concrete under impact loading**, *Magazine of Concrete Research*, **30**, *105*, Dec. 1978, 189-199.

A drop-hammer test was used to measure the compressive strength, ultimate strain, energy absorption, and deformation modulus of concrete cubes under impact loading. By assuming a trapezoidal function for both the hammer impact pulse and the cube impedance function, hypothetical load and strain records are derived which are similar to the initial experimental records measured on an oscilloscope. Concretes with varying mix proportions and two different coarse aggregates were examined, and the results for compressive strength and ultimate strain are reported.

● 6.2-60 Gulkan, P., Mayes, R. L. and Clough, R. W., **Strength of timber roof connections subjected to cyclic loads**, *UCB/EERC-78/17*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1978, 131.

This report examines the behavior of typical timber roof connections used in single-story masonry residential construction subjected to cyclic loads. In order to assess the adequacy of connections in transferring roof inertia loads developed during earthquake ground motions, five basic types of roof-to-masonry wall connection mock-ups comprising a total of 19 models were subjected to displacement controlled load tests using both in-plane (along the wall) and out-of-plane (transverse to wall) forces. The five types

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of connections contained load bearing and non-load bearing connection details of both gabled truss and flat roof construction. Behavior of the connections is described in terms of the deformations of the various components comprising the assembly. By examining the mode of failure and the code-allowable loads on bolted and nailed connections, the margin of safety inherent in current code requirements is determined. From the test results, it appears that the connection of the truss rafters to bearing and non-bearing walls, as implemented in the program, is adequate. However, for connections employing ledgers, supplementary anchorage devices need to be used since bolts tend to fail by pulling out of the face shell of the masonry units and ledgers fail easily when subjected to cross grain tension.

6.2-61 Rao, D. K., **Frequency and loss factors of sandwich beams under various boundary conditions,** *The Journal of Mechanical Engineering Science,* **20,** *5,* Oct. 1978, 271-282.

A complete set of equations of motion and boundary conditions governing the vibration of sandwich beams is derived by using the energy approach. The equations are solved exactly for important boundary conditions. The computational difficulties encountered in previous attempts to find the exact solutions of these equations are overcome by careful programming. These exact results are presented in the form of design graphs and formulas, and use of the results is illustrated by examples.

● 6.2-62 Kubota, T. and Sozen, M. A., **A study of methods used in Japan and the U.S.A. for design of web reinforcement in reinforced concrete,** *UILU-ENG-78-2013, Structural Research Series No. 452,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, Aug. 1978, 141.

Methods included in the specifications of the Architectural Inst. of Japan (AIJ) and the American Concrete Inst. (ACI) for design of web reinforcement were studied. The relative probabilities of flexural and shear failures are evaluated in reinforced concrete beams and columns proportioned on the basis of the AIJ and ACI methods.

● 6.2-63 Sheppard, P., Tercelj, S. and Turnsek, V., **The flexural resistance of masonry walls to combined horizontal and vertical loads,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-35, 1978, 279-286.

The results of flexural resistance tests of masonry walls are presented. The dimensions and quality of the walls were chosen so that flexural failures would occur upon crushing of the compressed corners of the walls. The results of these tests, in comparison with the theoretically predicted values of loads and deformations, provide a basis for using a simplified condition to design against flexural failure; the condition is valid for all vertical loadings that commonly occur.

● 6.2-64 Rochlin, I. A., **On seismic stability of constructions made of ceramic stones,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-34, 1978, 271-278.

The use of hollow ceramic blocks for buildings located in seismically active areas is discussed. The paper points out that the use of ceramic blocks decreases wall mass, thereby increasing building effectiveness. It also reduces consumption of cement and steel. The strength of the ceramic blocks is analyzed and compared to the strength of concrete and iron.

● 6.2-65 Tanaka, Y. *et al.,* **The shear strength of reinforced fiber concrete short columns,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-21, 1978, 167-174.

The shear strength of short concrete columns reinforced with steel fiber and the effect of the fiber reinforcement on the shear bearing mechanisms are discussed and their behavior compared to that of ordinary short reinforced concrete columns. It is concluded that fiber reinforcement is more effective than tie reinforcement in preventing brittle failure of core concrete, but that fibers cannot be substituted for ties because tie reinforcement maintains shear strength and prevents loss of rigidity during shear reversals.

● 6.2-66 Plichon, C., **Reinforced elastomers and friction supports: modern methods of antiseismic support,** translated by Patricia Newman, *SAND78-6001,* Technical Translation Service, Sandia Labs., Albuquerque, New Mexico, Jan. 1978, 38. (Translation of "Les elastomeres frettes et les appuis a friction: moyens modernes de supportage antisismique." Originally issued in *Proceedings of the Specialist Meeting on the Antiseismic Design of Nuclear Installations,* OECD, Paris, Dec. 1975, 203-227.)

The advantages of suspending a building or a group of buildings by elastic supports of artificial rubber are discussed briefly. These supports, which are used commonly to support prestressed concrete bridges in Europe and particularly in France, decouple heavy structures from horizontal seismic excitation. This decoupling limits the horizontal acceleration to a prespecified value and completely eliminates rocking movements. Seismic calculations for materials are substantially simplified since the peak floor response spectrum is at a frequency much below that of the materials. If the earthquake is quite severe, a horizontal friction surface is added to the elastic supports. This introduces a nonlinearity that can be controlled perfectly and permits an ordinary structure to support an arbitrary horizontal acceleration.

● 6.2-67 Tomii, M. and Ohno, H., **Practical calculation method of the stiffness matrix of framed shear walls,** *Memoirs of the Faculty of Engineering, Kyushu University,* 38, *3,* Sept. 1978, 219-247.

● 6.2-68 Aslam, M., Godden, W. G. and Scalise, D. T., **Rocking and overturning response of rigid bodies to earthquake motions,** *LBL-7539, UC-11,* Lawrence Berkeley Lab., Univ. of California, Berkeley, Nov. 1978, 88.

This report is a fundamental study of the rocking and overturning response of massive concrete blocks with a relatively high aspect ratio to simultaneous horizontal and vertical earthquake ground motions. Such blocks, stacked in various configurations, are used to provide radiation shielding in particle accelerator laboratories. While this study concerns large concrete blocks, any massive equipment presents a similar problem to the structural engineer. The results of this study offer insight into the response of any rigid bodies which are not anchored to the ground.

The mathematical model used was based on the assumption of a constant coefficient of restitution. A computer program was written to predict the rocking and overturning behavior of rigid rectangular blocks under simultaneously applied horizontal and vertical ground accelerations. To check the accuracy of the computer model, tests were carried out on a 20 ft x 20 ft shaking table at the Univ. of California, Berkeley. Free vibration tests and forced vibration tests were conducted under the effect of simultaneously applied horizontal and vertical accelerations. A satisfactory agreement was found between the test results and the theoretical calculations. The response of rigid blocks of various aspect ratios and sizes was studied with the computer program using the accelerograms of various strong-motion earthquakes. The coefficient of restitution was varied to examine its effect on the rocking response. The angular displacement, velocity, and acceleration response of the blocks to various accelerograms were plotted on the Calcomp plotter. The consequences of prestressing the massive concrete blocks to the floor were also studied. It is recommended that radiation shielding systems be prevented from rocking either by prestressing the blocks to the ground or by reducing friction between the block and the floor, thus allowing the block to slide.

● 6.2-69 Aslam, M., Godden, W. G. and Scalise, D. T., **Earthquake rocking response of rigid bodies,** *LBL-7983,* Lawrence Berkeley Lab., Univ. of California, Berkeley, Aug. 1978, 35.

This report describes an analytical and experimental study of the earthquake-induced rocking and overturning response of rigid blocks, a common problem in planning for seismic safety. This study, together with a previously reported study of the earthquake sliding response of rigid bodies, was initiated to establish safe design criteria for radiation shielding systems under strong-motion earthquakes. A good agreement is shown between theoretical predictions and shaking table tests on concrete blocks using simultaneous horizontal and vertical harmonic table motions. Using a computer program, the rocking and overturning response of rectangular blocks of various sizes and aspect ratios is studied under several strong-motion earthquakes. The effects of coefficient of restitution and of vertically prestressing the blocks to the floor are also studied. This investigation was undertaken primarily to study the response of solid concrete block stacks used as radiation shields in particle accelerator laboratories. Results from this study indicate that rocking should be prevented in such systems because of the danger of overturning once rocking commences, unless a tie-down design is used. The paper also points out the sensitivity of overturning to small changes in the base geometry and the coefficient of restitution as well as to the particular type of ground motion. This suggests that it may be difficult to use data from observations on standing and overturned rigid bodies after an earthquake to provide much useful information on the intensity of ground motion.

● 6.2-70 Hangai, Y. *et al.*, **Oscillation of cantilever cylindrical shells with a rectangular opening** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 132, Nov. 1978, 1049-1056.

The paper deals with the static and dynamic behavior of cantilever cylindrical shells with one rectangular opening. A static experiment, a vibration-generator test and numerical analysis by the finite element method are carried out. A multidirectional loading apparatus for the static experiment is developed to check the nonuniform displacements at each loading point. Test cylinders are made of acrylate resin, with a radius of 5 cm, height of 20 cm, and thickness of 0.3 cm. Displacements and strains of test cylinders with no opening and with openings of four kinds are measured for three loading conditions: (1) axial loading, (2) lateral loading in the same direction as the opening, and (3) lateral loading in the direction perpendicular to the opening. Using the results, the effect of an opening on the decreasing ratio of rigidity, deformation behavior, stress intensity, etc. is examined, and it is found that the opening angle has a strong influence upon the decrease of stiffness in comparison with the two cases with the same area of opening. In order to investigate the effect of an opening upon natural frequencies and vibration modes, the same cylinders are tested by using a vibration generator. Response curves, including various resonance points, are

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determined. From these curves, it is concluded that: (1) The opening angle has a stronger influence on the decrease of natural frequency of the first order than the height of opening. (2) The relative increase from the lower frequency to the upper becomes more pronounced as the opening angle becomes wider. Test cylinders are analyzed by means of the finite element method, and experimental and calculated results are compared.

● 6.2-71 Saito, A. *et al.*, **Behavior of a vibration isolated system** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 113, Nov. 1978, 897–904.

A horizontal slide mechanism was installed between a large coke oven and its foundation across the entire boundary surface. This mechanism consisted of graphite grease (a mixture of graphite and grease) and was designed mainly to release thermal stress. It was also anticipated that the system would have a vibration isolating effect. The excessive deflection of the boundary layer was a matter of concern. This paper presents the results of a dynamic test and an analysis carried out to study both the frictional phenomenon of the material and the dynamic behavior of the structure during earthquake ground motions. The tests consisted of dynamic material tests, model tests carried out using a shaking table, and field tests. The validity of the analysis was examined by comparing the experimental data and the results of the numerical analyses. Based on the following facts, the design of the slide mechanism was partially modified.

Viscocity greatly influenced the frictional phenomenon of the sliding mechanism. The coefficient of friction increased as the velocity of the structure increased. Both frictional and viscous phenomena must be considered. The friction coefficient depended on the normal load. The coefficient had a tendency to decrease as the normal load increased. The coefficient of the actual structure was smaller compared with the coefficient obtained from the experimental study carried out using the smaller model. The slide mechanism was effective as a vibration-isolation system because it reduced the acceleration and the inertia force of a structure subjected to earthquake ground motions. By using a spring, excessive deflection can be controlled without loss of the vibration isolating effect.

● 6.2-72 Ando, K., Ogura, N. and Kobori, T., **On the allowable defect size in steel structure for earthquake motions. (J-integral approach to elastic-plastic fatigue crack growth and transition behavior from stable to unstable crack propagation)** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 169, Nov. 1978, 1345–1352.

Fatigue crack growth and fatigue fracture toughness tests were performed on compact tension specimens of SM50 steel at 160~300° K. A new parameter, J_{max}, is proposed to analyze elastic-plastic fatigue crack problems. J_{max} values are estimated on the basis of the three-parameter method proposed by Garwood et al. using the envelope of load versus deflection hysteresis loops. ΔJ values are determined from the load versus the deflection hysteresis loops. For small-scale yielding conditions, J_{max} shows good correlation with the maximum stress intensity (K_{max}). The critical values of J_{max} are denoted as fatigue fracture toughness (J_{fc}). J_{fc} is independent of maximum load P_{max}, but does depend on the stress ratio (R) and the testing temperature. J_{fc} shows a clear transition temperature. This transition temperature depends on the stress ratio, and it increases with a decreasing stress ratio (R).

In the tension compression test, J_{fc}, at all temperature ranges sampled, shows a smaller value than the fracture toughness (J_c), generally being about a quarter of J_c. In the design of steel structures which are subject to earthquake motion, fatigue fracture toughness, rather than fracture toughness, should be taken into account. Fatigue crack propagation rates during gross plasticity can be predicted by combining ΔJ and J_{max}, which shows good agreement with the linear extrapolation of linear elastic fatigue crack propagation data. These experimental results suggest that J_{max} is a useful parameter for gross plastic fatigue crack problems. The allowable defect size is calculated based on fatigue fracture toughness.

● 6.2-73 Shimogo, T., Nakano, M. and Tateoka, J., **Seismic response of EHV gas insulated switchgear,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 154, Nov. 1978, 1225–1232.

This paper describes a dynamic study for the seismic-resistant design of an extremely high voltage and heavy current gas insulated switchgear (12,000 A, 500 kV). The dynamic model of the structure is proposed on the basis of vibration testing results obtained by using continuous sinusoidal wave excitation and three cycles of sinusoidal wave excitation at resonance. The structural parameters and the frequency response functions are estimated by means of the dynamic model. The amplification factor of each component of the structure was evaluated for the excitation of the three cycles of sinusoidal waves at the fundamental resonance frequency (about 5 Hz) by using the dynamic model. The effects on the amplification factor of the variation of the structural parameters of each component were examined. The amplification factor of the root mean square acceleration for the excitation of the band-limited stationary white noise and the amplification factor of the maximum acceleration for the El Centro earthquake waveform were also obtained by a theoretical calculation and a digital simulation, respectively.

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● 6.2-74 Wakabayashi, M. *et al.*, **Effect of strain rate on stress-strain relationships of concrete and steel**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 165, Nov. 1978, 1313-1320.

An experimental study is described of the effects of strain rate on the fundamental mechanical properties of the component materials of reinforced concrete structures subjected to earthquake load. The load was applied monotonically or cyclically to a specimen at a prescribed strain rate. The range of strain rates for the dynamic loading was between 0.005/sec. and 0.1/sec., with the fundamental periods of actual reinforced concrete structures taken into consideration. The compressive strength of concrete increases with an increase in the strain rate. On the other hand, a geometrical stress-strain curve configuration and the strain at maximum stress are little affected by the strain rate. In the case of repeated loading, no significant difference in the stress-strain relationship during one to ten cycles of loading is observed in the stress range lower than two thirds of compressive strength; accumulation of strain is observed in the higher stress range. From tension tests on steel bars, it is observed that yield stress increases with an increasing strain rate, accompanying the increase of strain at the beginning of strain-hardening. However, the behavior in the strain-hardening region and the strain at breakage are not greatly affected by strain rate. There is no significant difference between the envelope curves of stress-strain relationships under repeated loading and the stress-strain curves under monotonic loading.

● 6.2-75 Shimazu, T. and Fujinami, T., **In-plane resistance of reinforced concrete slabs with girders**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 168, Nov. 1978, 1337-1344.

This paper discusses experimental studies conducted to obtain basic information on the in-plane resistance of reinforced concrete slabs with side girders. Eight specimens, built to one-fifth scale of the example slabs in the Reinforced Concrete Code of Japan, were subjected to reversing horizontal loads under constant vertical loads. Variables considered were length-width ratio, the level of vertical loading applied, the amount of flexural reinforcement of the side girders, and the amplitude of the reversing deflection. The relationships of these variables are considered. Stiffness, strength, failure modes, and hysteresis loop characteristics of the slabs under horizontal loading and the ultimate strength of the slabs under vertical loading after being subjected to reversing horizontal loads are discussed.

● 6.2-76 Tsuchiya, H., **The effects of vertical motion of earthquake on building** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 137, Nov. 1978, 1089-1096.

Changes in the axial stresses of columns during an earthquake affect the flexural and shear capacities of a structure and reduce its ductility. Judging from recent damage to structures, caused when the strongest ground motion occurred at a structural site, a building is strongly affected by vertical and horizontal motion. This is especially true for shear failures of girders and slabs and for story collapses caused by column failures. Correlation of vertical and horizontal acceleration records has been investigated. It is suggested that in a region of a certain radius from an epicenter and with a certain earthquake magnitude function maximum vertical acceleration is the same as maximum horizontal acceleration. In earthquake records of this type, an apparent difference was observed in the change in time histories of the absolute acceleration values and the acceleration response spectra between two groups of earthquakes, the epicenters of which were about 10 km and 20-50 km away from the place where the earthquakes were recorded. Considering this, the author constructed six artificial waves to use as input for structural analysis. Vertical and horizontal motions are considered to be two-dimensional and elastic. This is accomplished by separately taking out each column with adjacent floors and girders and by setting up four models for response analysis: two for the outer end columns in the direction of the earthquake motions, one for the inner columns, and the remaining one for the corner columns.

The paper presents seismic coefficients of the axial stress for three types of columns and the shear stress response spectra for adjacent floors and girders. The maximum value of each model and the response spectra are shown. The preliminary response analysis demonstrates that motions of adjacent floors and girders strongly affect the axial stress of the columns, except that of the inner column, and that the coefficients of axial stress and shear stress become large for earthquakes not anticipated. To protect buildings from damage of this type, it is important to reduce the permanent axial stress of the columns and to increase the capacities of the slabs and girders.

● 6.2-77 Koh, T., Hasegawa, Y. and Kanetika, M., **Transfer functions and floor response of uniform frames** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 136, Nov. 1978, 1081-1088.

Transfer functions for uniform shear-type buildings are derived as general solutions of finite difference equations. Using these transfer functions, vibration characteristics and earthquake response of buildings of various stories are investigated. The floor response spectra of each building are also calculated for typical strong earthquake records.

Spectral characteristics of the floor response tend to depend mainly on the vibration characteristics and on the position of the floors rather than on the input earthquakes. The overturning and slip phenomena of rigid bodies on the floors are investigated using synthetic earthquake records. In the case of low buildings, small-sized rigid bodies are overturned mainly because of the large amplitude of the floor accelerations, while the large-scale bodies in high-rise buildings are likely to overturn because of the long periods of the accelerations. For the buildings with excessively low stiffness and weight at some stories, the general expressions of the transfer function are derived in the same manner as for uniform frames by considering the boundary conditions between a story with normal stiffness and weight characteristics and a story with excessively low characteristics. Using these expressions, the vibration behavior of penthouses and gyrating structures are studied as a coupled system having two kinds of weight-stiffness and damping ratios.

● 6.2-78 Nakagawa, S., Komori, K. and Kishimoto, T., **Earthquake response analysis on 10-span continuous bridge** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 133, Nov. 1978, 1057-1064.

A 10-span continuous expressway bridge has been constructed. Each span length is 50 m and the total length is 500 m. Earthquake response analysis in the longitudinal as well as the transverse direction is carried out to investigate the dynamic behavior of a long bridge. The bridge is designed so that the middle piers have a great deal of flexural rigidity and so that the flexural rigidity is decreased in steps toward both end piers. The purpose of this is to distribute uniformly earthquake and temperature loads.

The analysis is performed by means of the modal analysis method with an input acceleration of 255 gal at the base of the foundation footing. This intensity corresponds with that of the static design principle. From this dynamic response analysis, the following results are obtained. (1) The shaking mode of the first order is predominately longitudinal when the entire structure behaves as a one-mass-spring system. (2) Transverse vibration involves several predominant shaking modes. The variation of the rigidity of each pier during these modes affects the resulting response characteristics. (3) The bending moment at the pier base during shaking in a longitudinal direction is almost equal to or slightly lower than that of the static design, showing that it is reasonable to employ the static design principle for shaking in the longitudinal direction. However, because of complicated response behavior during transverse shaking, a dynamic response analysis is necessary. (4) Prediction of the natural period of longitudinal shaking shows good accuracy by the simplified formula, whereas less accuracy is obtained for the transverse shaking unless the rigidity of the super-structure as well as that of the piers is taken into account in the simplified formula.

● 6.2-79 Imai, H. and Kosugi, K., **Properties of shear walls after cracking (method of analyzing indirectly measured values and example of application)** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 161, Nov. 1978, 1281-1288.

This paper presents a method for the analysis of shear walls with structural steel frames. The method is based on the least squares theory of errors and matches directly measured strains and external forces on nodal points to determine deformation, stress, and hysteresis characteristics of the structural members in the plastic range. Analytical values are determined from directly measured experimental data, and, therefore, are called "indirectly" measured values. The theoretical values correspond well with the directly measured values.

The method is applied to specimen walls, and the analytical results may be summarized as follows: (1) wall concrete is in a pure shear stress state before cracking; (2) after cracking, wall concrete forms compression fields and pushes the peripheral frames outward; (3) when the wall-reinforcement ratio is high, the wall reinforcing bars act as tension diagonals with a yield point corresponding to the tensile strength ${}_cF_t$ of concrete; (4) for shear walls with structural steel frames, the rigidity of the frames after the walls crack may be evaluated by considering the elasticity of the structural steel; and (5) axial forces are predominant for the peripheral frames, and bending moments are small. At the final stage, the shear forces become fairly large.

● 6.2-80 Kaneta, K., Kohzu, I. and Hanabuchi, Y., **On the strength and ductility of welded beam-column connections subjected to low-cycle elasto-plastic deformations** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 170, Nov. 1978, 1353-1360.

It is important to study low-cycle fatigue failure in order to examine the safety of steel structures subjected to severe earthquake motions. This paper reports on the experimentally obtained cyclic inelastic actions and low-cycle fatigue properties of idealized welded beam-column connections. Specimens, consisting of JIS SS41 plates, were welded and fabricated into flat plate shapes which were named A-Type, or crossed shapes named B- or C-Type. Three types of specimens were loaded quasi-statically at constant amplitudes from ± 0.5% to ± 1.5% as deformations between the gauge length. Only C-Type specimens were subjected to constant bi-axial forces with a special loading apparatus. Brittle failures at locations near the column flanges occurred in A-Type specimens; ductile failures occurred at the same points in B- and C-Type

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specimens. No deteriorations from the effect of bi-axial forces were observed in C-Type specimens, but a few of these specimens experienced local buckling at the range of high bi-axial forces and large elastoplastic deformations even though the energy absorption capacity of the specimens was high. Records of electrically resistant wire gauges located at the column flanges, beam flanges, and stiffeners express the local buckling behavior of C-Type specimens. It is concluded that cyclic load-displacement curves (or cyclic nominal stress-strain curves) of A and B-Type specimens can be approximated well with bilinear models using an approximate bilinear skeleton curve and energy dissipation concepts. The low-cycle fatigue life of each strain amplitude is estimated for B- and C-Type specimens, and the coefficients are compared with the results of past tests of cylindrical specimens.

● 6.2-81 Cheng, F. Y., **Dynamic matrices of beams on elastic foundations,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 203-207.

A method is presented to describe the relationship between a transport matrix, a flexibility matrix, and a stiffness matrix when applied to the dynamic analysis of a beam on an elastic foundation.

● 6.2-82 Fujimoto, S., Shimogo, T. and Arii, M., **Aseismic design of 500KV air circuit breaker with friction dampers,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 125-132.

For the purpose of establishing a seismic resistant design evaluation method for a 500 KV air circuit breaker, the effects of the structural parameters on the seismic response are studied. The study was conducted by analytical methods, digital simulation, and experimental procedures using simplified models under various excitations. The following results were obtained. Although the bending moment of the support column decreases with the high initial tension of the stays or the high frictional force of the dampers, the acceleration response of the interrupting chamber and the tensile stress produced at the stays have minimum values at the specified initial tensions of the stays. If the stiffness of the support column increases, the tensile stress produced at the stays decreases. The acceleration response of the interrupting chamber and the bending moment of the support column have minimum values at certain stiffnesses of the support column, unless the resonance frequency of the structure coincides with the dominant frequency of the input seismic wave.

● 6.2-83 Hegemier, G. A. *et al.,* **Prism tests for the compressive strength of concrete masonry,** *North American Masonry Conference Proceedings,* Paper No. 18, 17. (For a full bibliographic citation, see Abstract 1.2-12.)

Results of an experimental program on concrete masonry prisms are presented. Current masonry industry testing procedures, potential problems with these procedures, and the influence of prism height, capping, bond configuration, and bearing-plate thickness are discussed. Modifications of existing codes are recommended.

● 6.2-84 Miller, M. E., Hegemier, G. A. and Nunn, R. O., **The influence of flaws, compaction, and admixture on the strength and elastic moduli of concrete masonry,** *North American Masonry Conference Proceedings,* Paper No. 17, 17. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper reports the results of tests conducted to determine the effects of admixtured grout and vibration compaction on the strengths and elastic moduli of unreinforced concrete masonry under field and controlled slump conditions. Four specimen groups consisting of two grout types, standard and admixtured, and two compaction types, puddled and vibrated, were fabricated and subjected to more than 90 tests. Flaws in the form of grout bridges are shown to seriously degrade uniaxial strengths and elastic moduli, based on prediction of assemblage properties from component data. Use of admixture and vibration under field conditions is discussed, and recommendations are made based on test results.

● 6.2-85 Nuss, L. K., Noland, J. L. and Chinn, J., **The parameters influencing shear strength between clay masonry units and mortar,** *North American Masonry Conference Proceedings,* Paper No. 13, 27. (For a full bibliographic citation, see Abstract 1.2-12.)

An investigation of the shear strength between clay masonry units and mortar is described. An effective and easily performed joint shear test is related from which the shear strength of masonry joints can be determined. Quantitative results from the tests showed the influence of mortar strength, mortar water content, mortar mix proportions, and clay unit water suction rate on shear strength. Linear and quadratic polynomial equations relating shear strength to joint normal compressive stress are fitted to the test data. Multiple regression techniques are used to relate shear strength to multiple masonry parameters in a single equation.

● 6.2-86 Harris, H. G. and Becica, I. J., **Behavior of concrete masonry structures and joint details using small scale direct models,** *North American Masonry Conference Proceedings,* Paper No. 10, 18. (For a full bibliographic citation, see Abstract 1.2-12.)

A methodology for small-scale direct models of concrete masonry structures is presented. Basic strength evaluation tests for compressive, flexural bond and shear strengths recommended for prototype structures are developed, with minor modifications for the evaluation of model

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masonry strength. A systematic analysis of the parameters which affect the strength and stiffness of masonry under compressive, flexural, and shear loadings provides a means of comparing model and prototype test results. Correlation of the model and prototype results ranges from excellent to good. For the case of masonry in compression, the testing of prisms shows that the model masonry behavior is essentially the same as that reported for prototype tests. Model tests on larger compression components also show good correlation with prototype data. In the case of flexural bond and shear strength of masonry, proper considerations must be given to the tensile strength of the joint mortar, including the effects of the stressed volume. This implies that very small-size control specimens, i.e., cubes or cylinders, must be tested in order to be sure that the small volume of the model joint bears the same relation to its control specimen as the volume in the prototype mortar joint bears to its respective control specimen. The correlation of model and prototype masonry strength tests for evaluating flexural bond and shear are shown to be satisfactory.

Excellent correlation of the elastic modulus of concrete masonry in compression and shear was obtained from the model tests and the limited stress-strain data of prototype masonry reported in the literature. This work has produced a systematic approach to the direct modeling of concrete masonry structures. Extensions of this approach to the study of joint details between masonry bearing walls and precast floor/roof systems are also demonstrated. The versatility of this approach for studying the inelastic behavior of concrete masonry structures in a direct and relatively inexpensive manner is indicated.

● 6.2-87 West, H. W. H., **Current masonry research at the British Ceramic Research Association,** *North American Masonry Conference Proceedings,* Paper No. 6, 13. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper describes research conducted on the structural performance of masonry (including concrete blocks), particularly resistance to lateral forces when the walls have no precompression; the interaction of floors and walls; the effects of openings; and the contribution of straps and ties. Also described are the compressive strength of calcium silicate brick walls under axial loading, the determination of the flexural strength of masonry in two orthogonal directions to establish the parameters to be used in design, and confirmation of the design theory by tests of the lateral strength of full-sized walls.

● 6.2-88 Nunn, R. O., Miller, M. E. and Hegemier, G. A., **Grout-block bond strength in concrete masonry,** *North American Masonry Conference Proceedings,* Paper No. 3, 9. (For a full bibliographic citation, see Abstract 1.2-12.)

Results of a series of shear tests on cores taken from masonry walls are presented. The influences of wall height, grout admixture, and vibration compaction are discussed. It is found that standard puddled grout produces a large proportion of zero-strength bonds, and that this problem is nearly eliminated through the use of admixture and vibration. Photographs illustrating grout-block separation and face shell spallation are included.

6.2-89 Bert, C. W. and Chen, T. L. C., **Effect of shear deformation on vibration of antisymmetric angle-ply laminated rectangular plates,** *International Journal of Solids and Structures,* 14, 6, 1978, 465-473.

The title problem is solved in closed form for simply supported edges. A displacement formulation of the heterogeneous shear-deformable plate theory, originated by Yang, Norris, and Stavsky, is used. Material properties, typical of a highly directional composite material (high-modulus graphite/epoxy) are used, and numerical results are presented showing the parametric effects of aspect ratio, length/thickness ratio, number of layers, and lamination angle. The effects of deleting rotatory inertia and in-plane inertia, singly and in combination, were also investigated. The information should be useful to composite-structure designers, to researchers seeking better correlation between theory and experiment, and to numerical analysts investigating finite-element programs.

● 6.2-90 Mattock, A. H., **Shear transfer under cyclically reversing loading, across an interface between concretes cast at different times,** *SM 77-1,* Dept. of Civil Engineering, Univ. of Washington, Seattle, June 1977, 98.

This study concerns the shear transfer strength of reinforced concrete subject to both single direction and cyclically reversing loading, the latter simulating earthquake conditions. The topics considered are the influence of the existence in the shear plane of an interface between concretes cast at different times, and the influence of the reinforcing bar diameter on shear transfer across a crack in monolithic concrete.

This section (Part 2) of the final report concerns shear transfer across the interfaces between concretes cast at different times and subject to cyclically reversing shear. Cyclically reversing and monotonic shear transfer tests of companion initially cracked specimens are reported. Both composite and monolithic specimens of normal weight concrete were tested. The interfaces of all composite specimens were roughened. In some cases, the bond at the interface was deliberately broken. It was found that, for a roughened interface with a good bond, the shear transfer behavior was similar to that of comparable initially cracked monolithic concrete. If the bond at the interface is broken,

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the shear transfer behavior under cyclic loading deteriorates rapidly, and the shear strength is only about 0.6 of that under monotonic loading.

● 6.2-91 Flandro, A. W., **A nonferrous reinforced concrete masonry structure,** *North American Masonry Conference Proceedings,* Paper No. 111, 10. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper investigates using nonferrous materials instead of steel to reinforce concrete masonry walls. Rods composed of aluminum, copper, and fiberglass resin are evaluated for strength, expansion coefficients, alkalinity resistance, availability, bonding characteristics, and cost. Fiberglass-resin rods proved to be the most satisfactory after a bonding problem was resolved during fabrication by the placement of a light sand upon rods while they were wet.

● 6.2-92 Haupt, W. A., **Isolation of vibrations by concrete core walls,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/14, 1977, 251-256.

The effect of isolating concrete core walls from surface wave motion is studied theoretically by use of the finite element method. With application of an influence matrix boundary condition, the size of the finite element field to be analyzed can be greatly reduced and a large number of finite element calculations, varying the dimensions of the wall and material properties, are economically feasible. The influence matrix boundary condition also assures continuity across the boundaries of the finite element field. The results show that the vibration-isolating effect of plane concrete core walls does not depend on the geometrical shape of the wall but only on the area of the cross section.

● 6.2-93 Yamada, M. and Tsuji, B., **Generalized stress-strain relationship of structural steel (Part I: isotropic-kinematic hardening model)** (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 17-22.

A new model is proposed for the analysis of elastic-plastic cyclic behavior of structural steels based on a modification of Prager's kinematic hardening model. During the plastic flow, this model behaves like the kinematic hardening model or the isotropic-kinematic hardening model. In the isotropic-kinematic hardening range, the combination parameter β is introduced. The isotropic hardening and the kinematic hardening behavior occur in the ratio of β and $(1-\beta)$, respectively. $\beta = 1$ corresponds to purely isotropic hardening and $\beta = 0$ corresponds to purely kinematic hardening. Cyclic hardening behavior is observed at the first few cycles because of the expansion and translation of the yield surface, after which steady state behavior is observed because of the translation of the yield surface under cyclic straining with constant strain amplitudes. A generalized constitutive relationship of the model is obtained. Considering the Bauschinger effect of the material, a series model is also proposed. This model consists of a collection of isotropic-kinematic hardening elements having different mechanical behaviors. The uniaxial stress-strain behavior of this model agrees fairly well with the experimental results obtained by Tanabashi et al.

● 6.2-94 Suzuki, S., Sugiyama, H. and Takemura, Y., **Behavior of the bearing wall in the wooden North-American-type full-size building (no. 1)** (in Japanese), *Transactions of the Architectural Institute of Japan, 269,* July 1978, 49-59.

This paper discusses the influence based on test results of racking test methods and wall length on the shearing properties of wooden bearing walls sheathed with 4 mm-thick plywood or 12 mm-thick insulation fiberboard. The test results of a full-scale building subjected to lateral force will be examined in a later paper.

● 6.2-95 Yamada, M. and Kawamura, H., **Resonance fatigue characteristics of structural materials and structural elements (part IV)—structural elements (2) experimental verification** (in Japanese), *Transactions of the Architectural Institute of Japan, 269,* July 1978, 73-83.

In this paper, the resonance fatigue characteristics of structural members which were idealized as NM and NQ models in a previous paper (Part III) are inspected qualitatively and quantitatively based upon experimental results. Reinforced concrete columns of the flexural yielding-type and reinforced concrete shear walls of the shear fracture-type are employed as test specimens for NM and NQ models, respectively. In accordance with the analytical predictions described in Part III, it is shown that constant deflection amplitude conditions result in the resonance response of reinforced concrete columns of the flexural yielding-type and that incremental deflection amplitude conditions result in the resonance response of reinforced concrete walls of the shear-fracture type.

● 6.2-96 Kaneko, Y. and Tanaka, Y., **Shear strength of reinforced concrete short columns (a study on shear failure mechanisms)** (in Japanese), *Transactions of the Architectural Institute of Japan, 267,* May 1978, 39-48.

The shear failure mechanisms of reinforced concrete short columns are investigated by use of shear transfer theory. It is assumed that the deformation of columns by shear loading is one of three types: flexural, bond failure, and shear slip deformation. The ultimate state is reached when the shear loading causes shear slip along diagonal tension cracks in core concrete and when yield confining forces in the tie reinforcing bars occur. Equations for the *ultimate shear strength of reinforced concrete short columns* are derived. The analytical results show good agreement with experimental results obtained by the authors and other researchers. It is concluded that sufficient tie reinforcement may make it possible to avoid shear failure in columns.

● 6.2-97 Shimodaira, H., **Study on isoparametric shell elements** (in Japanese), *Transactions of the Architectural Institute of Japan, 266*, Apr. 1978, 63–71.

This paper considers eight-node isoparametric shell elements. A formulation of the element stiffness matrix and a calculation procedure which reduces the amount of computation required are presented. The effects of reducing the order of integration of the element stiffness matrix are verified by numerical examples. Limitations of application of the element to thin shell analysis are investigated by numerical examples, and some criteria for use of the element are discussed. A method of calculating nodal stresses which is consistent with reducing the order of integration of the element stiffness matrix is presented. This method, the method using the conventional strain matrix, and Hinton's method are compared by using numerical examples.

● 6.2-98 Arai, Y., **Nonlinear analysis of a shear wall-frame systems of reinforced concrete** (in Japanese), *Transactions of the Architectural Inst. of Japan, 264*, Feb. 1978, 41–49.

This paper concerns the nonlinear analysis of reinforced concrete shear wall-frame systems by the finite element method. The applicability of the proposed method is discussed, by using several examples of numerical computations on existing experimental test results: (1) The biaxial stresses of concrete are determined as a function of principal strain in a state of plane stress on the basis of the experimental data by Kupfer, Hilsdorf, and Rusch. From the derived biaxial stress-strain relations, a solution of nonlinear equations of equilibrium by finite element analysis is obtained by employing an iteration method. (2) The concrete between cracks is capable of bearing tensile stresses because of the bond between the steel and the concrete, so that the reinforcing bars are restrained by the cracked concrete. By taking account of this restraining effect, the stiffness of the steel reinforcement in the cracked zone of the concrete is changed according to the amount of the average steel strain.

In comparison with test results, the proposed method appears to result in fairly good estimations of nonlinear load-deflection relations of shear wall-frame systems up to about 90% of their ultimate strength. In order to obtain better agreement between the analyses and experiments, it is necessary to clarify the physical conditions of stress transference and relative displacement along the cracks in the concrete.

● 6.2-99 Ino, S., **Dynamic properties of reinforced concrete floor slabs** (in Japanese), *Transactions of the Architectural Institute of Japan, 273*, Nov. 1978, 13–23.

An analytical method is presented to clarify the dynamic properties of a reinforced concrete slab vibrationally coupled with elements of a building frame. The results determined from instrumentation of many slabs, including damaged slabs, are discussed. The analytical method is used to theorize about various aspects of the behavior of actual slab systems under vibration.

6.2-100 Iyengar, K. T. S. R. and Raman, P. V., **Free vibration of circular plates of arbitrary thickness**, *The Journal of the Acoustical Society of America*, **64**, *4*, Oct. 1978, 1088–1092.

The free vibration of circular plates of arbitrary thickness is investigated using the method of initial functions. The state-space approach is used to derive the governing equations of the method. The formulation is such that theories of any desired order can be obtained by deleting higher terms in the infinite-order differential equations. Numerical results are obtained for flexural and extensional vibration of circular plates. Results are also computed using Mindlin's theory, and they are in agreement with the analysis.

6.2-101 Gomes de Oliveira, J. and Jones, N., **Some remarks on the influence of transverse shear on the plastic yielding of structures**, *International Journal of Mechanical Sciences*, **20**, *11*, 1978, 759–765.

The influence of transverse shear forces (Q) on the plastic behavior of beams is examined in this paper because of the need to establish yield curves which retain transverse shear effects important in some dynamic plasticity problems. It is suggested that an engineering compromise between the simple local (stress resultant) and more rigorous non-local (plane stress, plane strain) theories may be achieved for *I*-beams when using a local theory with a maximum transverse shear force based only on the web area.

● 6.2-102 Omote, Y. *et al.*, **A literature survey–transverse strength of masonry walls**, *UCB/EERC-77/07*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Mar. 1977, 145. (NTIS Accession No. PB 277 933)

The literature survey presented collates most of the available relevant information on the transverse or out-of-plane strength of masonry walls. The report discusses several of the test techniques used and summarizes the most significant available test results. Formulations for predicting the capacity of walls subjected to transverse loads are presented and correlated with experimental results. Also included is a section relating test results to present design practices and code requirements.

● **6.2-103** Egami, H., **Stress analysis of precast panel construction with particular reference to the stiffness of joints (2)** (in Japanese), *Transactions of the Architectural Institute of Japan, 263,* Jan. 1978, 33–41.

In a previous paper, the author formulated a theory of construction with elastic joints for the linear static analysis of precast reinforced concrete walls constructed with precast reinforced concrete blind panels. The method can be used to calculate the mechanical behavior of precast reinforced concrete walls subjected to the horizontal force of an earthquake. An analysis was carried out under the following assumptions: (1) The rigidity of blind panels is of infinite quality outside the rigidity of shearing. (2) The rigidity of expansion and shearing and bending in joints around the blind panels are considered. This paper calculates, by the above method, a theoretical value which agrees well with the result of the lateral loading of a precast reinforced concrete wall constructed of two precast reinforced concrete blind panels. The analysis is then extended under the following assumptions: (1) The rigidity of the panel zone members involves both horizontal joints and vertical joints. (2) The axial rigidity of the vertical joint members is infinite.

● **6.2-104** Imai, H., **Properties of reinforced concrete shear walls after shear cracking** (in Japanese), *Transactions of the Architectural Institute of Japan, 268,* June 1978, 9–20.

This paper concerns the properties of reinforced concrete shear walls after cracking in shear. It is shown that, after cracking, walls act as diagonal 45° compression members, while reinforcing bars act as tensile forces perpendicular to the diagonal wall members. As a result, the maximum resisting capacities of unconstrained shear walls without frames are determined by the amount of reinforcement in the walls, and may be expressed by an equation given in this paper. Two types of compressional shear failure in frames and walls are considered. The properties of shear walls with frames are analyzed, and it is shown that load-deformation curves and stress distributions of the frames coincide well with measured values.

● **6.2-105** Mead, D. J. and Bansal, A. S., **Mono-coupled periodic systems with a single disorder: free wave propagation,** *Journal of Sound and Vibration,* **61,** *4,* Dec. 22, 1978, 481–496.

A general method is presented for analyzing free harmonic wave propagation through a mono-coupled periodic system with a single disorder. Expressions are derived for the magnitudes of the waves transmitted and reflected by the disorder. These general expressions are then used to study flexural wave motion through a periodic beam system into which three different types of disorder have been introduced: (1) a beam element of non-periodic length; (2) a rotary mass at a support; and (3) a rotary spring at a support. The disorder always results in reduced transmission of the flexural wave when the frequency is in a frequency propagation zone of the periodic system, but the first two disorders may lead to increased transmission in a frequency attenuation zone. Conditions have been identified under which the combined disorder plus periodic system can behave like a resonating spring-mass system or as a spring-mass damper system. The adverse effects of resonating disorders are pointed out. Qualitative and quantitative analysis based upon computer studies has indicated how disorders can be used most effectively for vibration isolation in existing periodic systems or when designing new systems.

● **6.2-106** Irie, T., Yamada, G. and Narita, Y., **Free vibration of cross-shaped, I-shaped and L-shaped plates clamped at all edges,** *Journal of Sound and Vibration,* **61,** *4,* Dec. 22, 1978, 571–583.

This paper presents a new series-type method for solving the eigenvalue problems of irregularly shaped plates clamped at all edges. An irregularly shaped plate is formed on a simply supported rectangular plate by rigidly fixing several segments. With the reaction forces and moments acting on all edges of an actual plate of irregular shape regarded as unknown harmonic loads, the stationary response of the plate to these loads is expressed by the use of the Green function. The force and moment distributions along the edges are expanded into a Fourier series with unknown coefficients, and the homogeneous equations for the coefficients are derived by restraint conditions on the edges. The natural frequencies and the mode shapes of the actual plate are determined by calculating the eigenvalues and eigenvectors of the equations. The method is applied to a cross-shaped, an I-shaped, and an L-shaped plate clamped at all edges. The natural frequencies and the mode shapes of the plates are calculated numerically, and the effect of the shape is discussed.

● **6.2-107** Nayfeh, A. H. and Nassar, E. A.-A. M., **Simulation of the influence of bonding materials on the dynamic behavior of laminated composites,** *Journal of Applied Mechanics, ASME,* **45,** *4,* Dec. 1978, 822–828.

Two model analyses are constructed in order to determine the influence of bonding materials on the dynamic behavior of otherwise bilaminated composites. The geometric arrangement of the composite with the bond is treated as a special type of trilaminated composite in which each of its major constituents is sandwiched between two bonding layers. In the first model, the recently developed

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continuum mixture theories of wave propagation in bilaminated composites are extended to treat the trilaminated composite. Details of the propagation process in the major components and in the bonding layers are derived. In the second model, the entire effect of the bonds is treated as a modifier to interfacial continuity conditions. In this model, the details of the propagation process in the bonding material are ignored. It is found that the results of both models correlate well for relatively thin bonding layers.

● **6.2-108** Greenberg, J. B. and Stavsky, Y., **Axisymmetric vibrations of orthotropic composite circular plates,** *Journal of Sound and Vibration,* **61,** *4,* Dec. 22, 1978, 531–545.

A sixth-order system of equations of motion is formulated in terms of the radial and transverse displacements for axisymmetric vibrations of circular plates laminated of polar orthotropic plies. Previous results for heterogeneous isotropic circular plates are included as a special case in the present theory. It is shown that a coupling exists between extensional and flexural vibrations through the plate elastic coefficients and an inertia term given in the paper. The eigenvalue problem is solved numerically by using a finite difference method, and results are presented for various double- and triple-layer composites. The eigenfrequencies are found to be quite sensitive to material anisotropy and plate lay-up.

● **6.2-109** Laura, P. A. A. and Luisoni, L. E., **Vibrations of orthotropic rectangular plates with edges possessing different rotational flexibility and subjected to in-plane forces,** *Computers & Structures,* **9,** *6,* Dec. 1978, 527–532.

The title problem is solved using polynomial approximations and a weighted residuals approach. It is shown that a very simple, yet accurate, approximate fundamental frequency equation can be generated. A basic forced vibrations problem is also analyzed. The procedure is quite convenient for design purposes since all the resulting expressions for frequency coefficients, displacements, and stress resultants can be easily implemented for numerical evaluation in a programmable pocket calculator.

● **6.2-110** Sakata, T., **Natural frequencies of clamped orthotropic rectangular plates with varying thickness,** *Journal of Applied Mechanics, ASME,* **45,** *4,* Dec. 1978, 871–876.

The characteristic equation of a clamped orthotropic rectangular plate with thickness varying in one direction parallel to the side is derived analytically by the use of the double trigonometric series. By using the fundamental natural frequency determined from the characteristic equation, a formula is obtained numerically for estimating the fundamental natural frequency of a clamped orthotropic rectangular plate with thickness varying linearly in one direction. The accuracy of the formula and the influence of the flexural rigidity D_1 on the natural frequency are discussed.

● **6.2-111** Plunkett, R. and Sax, M., **Nonlinear material damping for nonsinusoidal strain,** *Journal of Applied Mechanics, ASME,* **45,** *4,* Dec. 1978, 883–888.

The damping in uniform and nonuniform cantilever beams was measured at resonance for a range of amplitudes of simultaneous steady-state first- and second-mode vibration. For two linear materials, aluminum and crossply fiberglass, the damping factor in each mode is independent of amplitude and unaffected by the presence of the other mode. For a fully annealed tool steel with highly nonlinear damping, the damping factor in each mode is markedly increased by the presence of the other mode.

● **6.2-112** Rao, G. V. and Raju, K. K., **Large amplitude axisymmetric vibrations of annular plates with edges elastically restrained against rotation,** *Computers & Structures,* **9,** *6,* Dec. 1978, 609–613.

Large amplitude axisymmetric vibrations of annular plates with the inner and outer edges elastically restrained against rotation are considered in this paper. A finite element formulation is used to obtain the effect of elastical restraints on the nonlinear to linear period ratios of annular plates of different radii ratios.

● **6.2-113** Gupta, U. S. and Lal, R., **Transverse vibrations of a non-uniform rectangular plate on an elastic foundation,** *Journal of Sound and Vibration,* **61,** *1,* Nov. 8, 1978, 127–133.

Free transverse vibrations of an isotropic rectangular plate of variable thickness resting on an elastic foundation is examined on the basis of classical plate theory. The fourth-order differential equation governing the motion is solved by using the quintic spline interpolation technique. Characteristic equations for plates of exponentially varying thickness are obtained for three combinations of boundary conditions at the edges. Frequencies, mode shapes, and moments are computed for different values of the taper constant and the foundation moduli for the first three modes of vibration.

● **6.2-114** Lang, K.-W. and Nemat-Nasser, S., **Vibration and stability of rectangular strip-plates,** *Journal of Sound and Vibration,* **61,** *1,* Nov. 8, 1978, 9–24.

The problem of free vibration and stability of a simply supported rectangular strip-plate subjected to constant inplane forces is considered. The relevant continuity conditions at the interface between the adjacent regions, which play a significant role in this type of problem, are derived. The eigenfrequencies and the buckling load are estimated by the method of the new quotient which is based on a

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variational statement proposed by Nemat-Nasser. The results are compared with those obtained by means of the usual Rayleigh quotient and the exact solution. The accuracy obtained by the application of the method of the new quotient is demonstrated by means of numerical examples.

● **6.2-115** Dickinson, S. M., **The buckling and frequency of flexural vibration of rectangular isotropic and orthotropic plates using Rayleigh's method,** *Journal of Sound and Vibration,* **61,** *1,* Nov. 8, 1978, 1-8.

A simple approximate formula for the natural frequencies of flexural vibration of isotropic plates, originally developed by Warburton using the characteristic beam functions in Rayleigh's method, is modified to apply to specially orthotropic plates and extended to include the effect of uniform, direct inplane forces. The initial buckling problem is treated simply by equating the frequency expression to zero. The approach permits the easy determination of reasonably accurate natural frequencies and/or buckling loads for a given plate involving any combination of free, simply supported or clamped edges, without requiring the aid of a sophisticated calculating device or a knowledge of plate, vibration, or buckling theory. To illustrate the applicability and accuracy of the approach, numerical results for a number of specific plate problems are presented.

● **6.2-116** Shih, P.-Y. and Schreyer, H. L., **Lower bounds to fundamental frequencies and buckling loads of columns and plates,** *International Journal of Solids and Structures,* **14,** *12,* 1978, 1013-1026.

A general derivation of expressions for lower bounds to fundamental frequencies and buckling loads is given for the class of structures governed by linear elastic theory in the prebuckling state. These expressions involve two Rayleigh quotients both of which are upper bounds for the fundamental frequency under a prescribed load. The displacement trial functions must satisfy force and kinematic continuity but no other conditions are required; thus, if appropriate high order base functions are used, the finite element procedure can be used to systematically narrow the difference between the upper and lower bounds. The theory is illustrated with several column and plate problems. The finite element method is applied to uniform and nonuniform columns with a representative set of boundary conditions. Elementary trial functions are used to show that reasonable bounds can also be obtained for plates subjected to known states of stress. Since the lower bound is obtained with a variation of the classical technique of Rayleigh, these results indicate that the method may be suitable for conservatively estimating buckling loads and fundamental frequencies of engineering structures.

● **6.2-117** Downs, B., **Reference frequencies for the validation of numerical solutions of transverse vibrations of non-uniform beams,** *Journal of Sound and Vibration,* **61,** *1,* Nov. 8, 1978, 71-78.

Tables of natural frequencies, calculated from exact analytical solutions, are presented for beams of various geometries including truncated tapered cantilevers and pretwisted uniform beams. Independent numerical solutions are used in several instances to confirm the accuracy which can be as high as six significant figures.

● **6.2-118** Nagashima, F. and Itoh, F., **A method of dynamic analysis of parallel chord space truss,** *Memoirs of Faculty of Technology, Tokyo Metropolitan University,* **28,** 1978, 2687-2696.

This paper describes a method for the dynamic analysis of a space structure—the parallel chord space truss—which possesses comparatively strong symmetry. The chief objective of the method is to reduce a degree-of-freedom of the system by using a suitable supposition and convenient variable transformation method so that the system retains the structural properties and is capable of analyzing a many degrees-of-freedom system, i.e., a long-span bridge structure. A five degree-of-freedom per cross section model system can be used for lateral vibration analysis, while a three degree-of-freedom model system is recommended for transverse vibration analysis.

● **6.2-119** Thompson, K. J. and Park, R., **Stress-strain model for grade 275 reinforcing steel with cyclic loading,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *2,* June 1978, 101-109.

The stress-strain relationship of Grade 275 steel reinforcing bar under cyclic (reversed) loading is examined using experimental results obtained from eleven test specimens to which a variety of axial loading cycles were applied. A Ramberg-Osgood function is fitted to the experimental stress-strain curves to follow the cyclic stress-strain behavior after the first load run in the plastic range. The empirical constants in the function are determined by regression analysis and are found to depend mainly on the plastic strain imposed in the previous loading run. The monotonic stress-strain curve for the steel, with the origin of strains adjusted, is assumed to be the envelope curve giving the upper limit of stress. The resulting Ramberg-Osgood expression and envelope are found to be in good agreement with the experimentally measured cyclic stress-strain curves.

6.2-120 Srinivasan, R. S. and Ramachandran, S. V., **Large-amplitude vibration of oblique panels,** *The Journal of the Acoustical Society of America,* **63,** *3,* Mar. 1978, 800-805.

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

This paper considers the large-amplitude free vibration of skew plates having variable thickness. Two governing nonlinear differential equations in terms of the lateral deflection and "force function" are derived in the oblique coordinates. The edges of the plate are assumed to be clamped and free to move in the plane of the plate. The differential equations and the boundary conditions are transformed into nonlinear algebraic equations by using the integral equation for beams along the oblique directions. These algebraic equations are then solved by the Newton-Raphson procedure. Numerical work is shown, and graphs showing period versus amplitude are presented for different values of thickness parameter, skew angle, and aspect ratio.

6.2-121 Shahinpoor, M., Tadjbakhsh, I. G. and Razani, A., **Estimates on seismic amplification factors of reactor components,** *Nuclear Engineering and Design,* **50,** *2,* Oct. 1978, 323-325.

Employing an averaging technique, estimates are obtained of seismic amplification factors for different components in nuclear reactors.

● **6.2-122** Kircher, C. A. *et al.,* **Seismic analysis of oil refinery structures (part I): experimental and analytical studies of tall columns,** *Technical Report 31,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Sept. 1978, 430.

This investigation concerns the seismic design and analysis of tall columns used in oil refineries. The principal purposes of this project are to obtain better information on the dynamic properties of tall columns by means of field measurements and analytical techniques, to reconcile these results, and to use these results in evaluating the criteria used in the seismic design of tall columns. The final technical report of this project appears in two volumes.

Part I contains a description of the four columns that were investigated, including the structures, foundations, and soil conditions. Also covered are the experimental program, analyses and data processing of the measurements, and the results of the measurements (natural frequencies, mode shapes, and damping). In the final sections, the theoretical modeling and results are presented, and the experimental and analytical results are compared. See Abstract No. 6.2-123 for Part II.

● **6.2-123** Scholl, R. E. *et al.,* **Seismic analysis of oil refinery structures (part II): evaluation of seismic design criteria,** *Technical Report 32,* John A. Blume Earthquake Engineering Research Center, Stanford Univ., Stanford, California, Sept. 1978, 54.

This second part of a two-part report describes the dynamic seismic analyses (including mathematical models and seismic input) of tall columns. Also presented are an equivalent lateral force analysis of a column and a discussion of current design procedures and their adequacy. See Abstract No. 6.2-122 for Part I.

● **6.2-124** Hegemier, G. A. *et al.,* **A major study of concrete masonry under seismic-type loading,** *Earthquake Response and Damage Prediction of Reinforced Concrete Masonry Multistory Buildings, UCSD/AMES/TR-77/002,* Dept. of Applied Mechanics and Engineering Sciences, Univ. of California, San Diego, La Jolla, Jan. 1978, 110.

This report constitutes an introduction to and a survey of an extensive Univ. of California, San Diego, research program on concrete masonry and the seismic response of concrete masonry structures. Objectives, scope, methodology, and utilization are discussed. Selected experimental, analytical, and numerical results are presented.

● **6.2-125** Derecho, A. T., Fugelso, L. E. and Fintel, M., **Structural walls in earthquake-resistant buildings: dynamic analysis of isolated structural walls—input motions,** Construction Technology Labs., Portland Cement Assn., Skokie, Illinois, Dec. 1977, 54.

The primary objective of the analytical investigation, of which the work reported here is a part, is the estimation of the maximum forces and deformations that can reasonably be expected in critical regions of structural walls 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 that is to be developed as the ultimate objective of the overall investigation.

This is the first part of the report on the analytical investigation. It deals mainly with the characterization of input motions in terms of intensity, duration, and frequency content. Accelerograms are classified with respect to frequency content as "peaking" or "broad band" depending upon the character of the associated velocity response spectra. It is shown that "spectrum intensity" is a good measure of ground motion intensity. The main purpose of the characterization is to enable the determination of maximum or critical dynamic response by using the least number of input motions in the analyses.

● **6.2-126** 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 the work reported here is a part, is the estimation of the maximum forces and deformations that can reasonably be expected in critical regions of structural walls in buildings subjected to strong ground motion. The results of

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the analytical investigation, when correlated with data from the concurrent experimental program, will form the basis for a design procedure to be developed as the ultimate objective of the overall investigation. This publication, the second part of a comprehensive report on the analytical investigation, discusses the results of parametric studies of various structural and ground motion parameters. 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 three strong-motion accelerogram parameters: duration, intensity, and frequency content.

● **6.2-127** Thompson, K. J. and Park, R., **Stress-strain model for prestressing steel with cyclic loading,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *4,* Dec. 1978, 209–218.

Experimental stress-strain curves for repeated tensile loading of 0.276 in. (7 mm) diameter prestressing steel wire in the inelastic range are presented. A mathematical model employing a modified form of the Ramberg-Osgood function is proposed to describe the cyclic stress-strain behavior of the prestressing steel. The experimental stress-strain results are subjected to regression analysis in order to obtain empirical expressions for the constants in the Ramberg-Osgood function. The constants are found to depend on the strain imposed in the previous loading run and the characteristics of the monotonic stress-strain curve. The stress-strain curve for monotonic loading, with suitably adjusted origin of coordinates in the case of significant reversed loads, is used to describe the envelope curve which the steel stresses cannot exceed. The proposed cyclic stress-strain model predicted the experimental curves with good accuracy.

● **6.2-128** Crespo da Silva, M. R. M. and Glynn, C. C., **Nonlinear flexural-flexural-torsional dynamics of inextensional beams. I. equations of motion,** *Journal of Structural Mechanics,* **6,** *4,* 1978, 437–448.

This paper is divided into two parts. The authors' purpose in Part I is to formulate a set of mathematically consistent governing differential equations of motion describing the nonplanar, nonlinear dynamics of an inextensional beam. The beam is assumed to undergo flexure about two principal axes and torsion. The equations are developed with the objective of retaining contributions resulting from nonlinear curvature as well as nonlinear inertia. A priori ordering assumptions are avoided as much as possible in the process. The equations are expanded to contain nonlinearities up to order three to facilitate comparison with analogous equations in the literature and to render them amenable to the study of moderately large amplitude flexural-torsional oscillations by perturbation techniques. The utilization of the order-three equations in the analysis of nonlinear beam oscillations is the subject of Part II (Abstract No. 6.2-129).

● **6.2-129** Crespo da Silva, M. R. M. and Glynn, C. C., **Nonlinear flexural-flexural-torsional dynamics of inextensional beams. II. forced motions,** *Journal of Structural Mechanics,* **6,** *4,* 1978, 449–461.

The nonplanar, nonlinear, resonant forced oscillations of a fixed-free beam are analyzed by a perturbation technique with the objective of determining quantitative and qualitative information about the response. The analysis is based on the differential equations of motion developed in Part I (Abstract No. 6.2-128) of this paper which retain not only the nonlinear inertia but also nonlinear curvature effects. It is shown that the latter play a significant role in the nonlinear flexural response of the beam.

● **6.2-130** Sato, H., **Nonlinear free vibrations of clamped beams with two symmetric steps** (in Japanese), *Memoirs of the Faculty of Technology, Kanazawa University,* **11,** *2,* Mar. 1978, 87–95.

The nonlinear characteristics of large-amplitude free vibrations of clamped-clamped beams with two symmetric steps are studied. Galerkin's method (one mode approximation) and the harmonic balance method (fundamental harmonic approximation) are used to obtain the solution. Beams with two different shapes, circular cross sections and constant-width rectangular cross sections, are considered. The effects of the diameter ratio between two sections and the effects of the length ratio (the ratio of the length of the middle element and the total length) on the nonlinearity are investigated under the restrictions that the weight and length of the beams are constant. The nonlinearity of the stepped beams studied is generally greater than that of uniform beams. With the increase of the diameter ratio, the maximum value of the magnitude of the nonlinearity caused by the change of the length ratio increases and also the length ratio corresponding to the maximum value approaches about 0.5. The linear natural frequencies and the maximum bending stresses at a maximum displacement are also discussed in connection with the nonlinearity.

● **6.2-131** Ariaratnam, S. T. and Srikantaiah, T. K., **Parametric instabilities in elastic structures under stochastic loading,** *Journal of Structural Mechanics,* **6,** *4,* 1978, 349–365.

The dynamic stability of nongyroscopic, elastic structures under parametric random loading of small intensity is investigated. Conditions for stability in the second norm of the dynamic response are obtained and shown to depend only on those values of the excitation spectral density near

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twice the natural frequencies and the combination frequencies of the structure. As an application, the flexural-torsional stability of a simply supported thin elastic beam subjected to stochastically fluctuating end couples is studied.

6.3 Dynamic Properties of Linear Structures

6.3-1 Harman, D. J. and Johnson, A. A., **Analysis of buildings with interconnected shear walls,** *Canadian Journal of Civil Engineering,* 5, *2,* June 1978, 157–163.

A method for analysis of interconnected shear walls that accounts for the torsional stiffness caused by nonuniform warping is described. Floor-to-floor plane wall members are idealized as part of the input to a three-dimensional frame analysis computer program. Where walls in different planes intersect, constraints insuring common vertical displacements are imposed. These constraints appear in the computer input as special types of members; however, within the solution, the Lagrangian multiplier method is used to process the constraint equations. A frontal method that handles the constraints efficiently along with members and loadings is used. The use of this method of analysis is simpler and more versatile than comparable methods. Most arrangements of shear walls that form open cross sections can be analyzed in conjunction with frames and other walls. Locating the shear center of groups of walls and determining their torsional properties are not required.

The results of this analytical method are compared to experimental results and to the results of other analytical methods. The accuracy of the proposed method depends upon the number of stories in the model because force transfer between adjacent wall segments occurs only at floor levels; in reality, a continuous transfer of force occurs through the height of the walls. In the opinion of the authors, using the proposed method for buildings of 20 or more stories would certainly provide adequate accuracy for design.

● 6.3-2 Coull, A. and Mukherjee, P. R., **Natural vibrations of shear wall buildings on flexible supports,** *Earthquake Engineering and Structural Dynamics,* **6**, *3,* May-June 1978, 295–316.

A shear wall building is considered as an assembly of plane and curvilinear shear walls tied together by floor slabs to act as a composite unit. Based on this conception and the continuous medium approach, the governing dynamic equations and boundary conditions are derived from energy principles, using Vlasov's theory of thin-walled beams. All primary and secondary inertia forces, as well as the influence of elastic foundation flexibility, have been taken into consideration. A numerical solution of the dynamic equations is achieved by employing the Ritz-Galerkin technique, yielding both natural frequencies and mode shapes. The technique is applicable to buildings containing coupled and noncoupled, open section shear walls oriented in plan in any arbitrary manner. The use of the method is illustrated by the example of a complex building with an unsymmetric plan, and the analytical natural frequencies of two shear wall building models are compared with those obtained experimentally by other investigators.

● 6.3-3 Cheung, Y. K. and Kasemset, C., **Approximate frequency analysis of shear wall frame structures,** *Earthquake Engineering and Structural Dynamics,* **6**, *2,* Mar.-Apr. 1978, 221–229.

The finite strip method is used to determine the natural frequencies of shear wall frame buildings. The structure can be modeled in two ways. In the first approach, the shear walls and the frames are idealized as an assemblage of finite strips of varying thicknesses with given or computed properties; in the second approach, the shear walls are still idealized as a series of finite strips, but the frames are regarded as a number of long columns which are interconnected either with each other or with finite strips through the horizontal beams. Numerical results obtained from both models indicate good agreement with finite element solutions. The proposed models can be applied to a wide range of shear wall frame assemblies and are therefore more versatile than most existing models.

● 6.3-4 Humar, J. L., **Eigenvalue programs for building structures,** *Computers & Structures,* **8**, *1,* Feb. 1978, 75–91.

This paper presents two eigenvalue routines for calculating the mode shapes and frequencies of engineered structures, particularly buildings. Both routines are based on the assumption that the mass matrix is diagonal, with all diagonal terms non-zero, and that the stiffness matrix is symmetric. The inverse power method with shifts is used in each case; the only important differences between the routines is in the allocation of storage and in the procedure used for inverting the matrices. Examples are presented to demonstrate the computational efficiency that can be achieved by using the inverse power method with shifts, provided the shift points are located judiciously and an appropriate convergence criterion is employed.

● 6.3-5 Mittal, A. K., **Stability of forced periodic response in third order non-linear systems,** *Journal of Sound and Vibration,* **58**, *4,* June 22, 1978, 579–585.

Conditions for the stability of the forced periodic response in third-order nonlinear systems are obtained after linearization. These conditions are consistent with results obtained by other methods.

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● **6.3-6** Szemplinska-Stupnicka, W., **The generalized harmonic balance method for determining the combination resonance in the parametric dynamic systems,** *Journal of Sound and Vibration,* **58,** *3,* June 8, 1978, 347–361.

For a multidegree-of-freedom system under parametric excitation, an attempt is made to generalize the harmonic balance method for the combination resonance. The two harmonic components solution with uncommensurable frequencies is assumed on the stability limits. It is found that, besides the condition of zero value of the characteristic determinant of the algebraic system derived by the harmonic balance procedure, the additional condition of vanishing of all minors must be satisfied. The method is applied to a two degree-of-freedom system. The boundaries of the principal periodic and combination resonances were calculated theoretically, and the results checked by an analog computer analysis. New essential features and peculiarities of the combination resonance are examined.

● **6.3-7** Abdel-Ghaffar, A. M., **Free lateral vibrations of suspension bridges,** *Journal of the Structural Division, ASCE,* **104,** *ST3,* Proc. Paper 13609, Mar. 1978, 503–525.

A method for calculating the free lateral vibrations of suspension bridges is developed. The method is based on a linearized theory and the finite element method. Two distinct steps are involved: (1) specification of the potential and kinetic energies of the bridge, and (2) use of the finite element method to (a) discretize the structure into equivalent systems of finite elements; (b) select the displacement model most closely approximating the real case; (c) derive the element and assemblage stiffness and inertia properties; and (d) form the matrix equations of motion and the resulting eigenproblems. A numerical example is used to investigate the dynamic characteristics of laterally vibrating suspension bridges. This method eliminates the need to solve transcendental frequency equations and simplifies the determination of the energy stored in different members of the bridge. It is a simple, fast, and accurate tool for calculating the natural frequencies and modes of lateral vibration by means of a digital computer.

● **6.3-8** Haris, A. A. K., **Approximate stiffness analysis of high-rise buildings,** *Journal of the Structural Division, ASCE,* **104,** *ST4,* Proc. Paper 13700, Apr. 1978, 681–696.

Developments in computer software have made many programs available for more exact highrise space-frame design. However, in practical structural engineering, such programs may be expensive and time consuming, especially for the preliminary design. This paper presents a reasonably accurate method to solve problems of lateral load distribution among the different frames of a highrise building by simple programming using small computers. The cantilever method for approximate lateral load analysis is incorporated to derive the flexibility and the stiffness matrices of each frame. By the method presented, the lateral loads are distributed among the frames according to the approximate stiffness matrix of each frame, and the final sway of the building can be found. This method can also be used for buildings with a combined system of frames and shear walls.

● **6.3-9** Gupta, K. K., **Development of a finite dynamic element for free vibration analysis of two-dimensional structures,** *International Journal for Numerical Methods in Engineering,* **12,** *8,* 1978, 1311–1327.

This paper develops an efficient free-vibration analysis procedure of two-dimensional structures. The procedure uses a discretization technique based on a recently developed concept of finite dynamic elements involving higher order dynamic correction terms in the associated stiffness and inertia matrices. A plane rectangular dynamic element is developed in detail. The numerical solutions of free-vibration analysis presented indicate that these dynamic elements, combined with a suitable quadratic matrix eigenproblem solution technique, effect an economical and efficient solution when compared with the usual finite element method.

● **6.3-10** Lipovskaya, V. Ja., Yarotskaya, L. V. and Yaryshev, B. P., **The application of ultrasound modelling for investigation of seismic processes in dams and their foundations,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-42, 1978, 321–327.

Presented are some problems in applying ultrasound modeling to investigate wave phenomena in nonuniform dams and their rock foundations. Using two-dimensional ultrasound modeling, the seismic field characteristics utilized for the estimation of the seismic stress state of the dams of the Toktogulskaya, Ingurskaya and Nurekskaya hydropower systems were investigated. The modeling was based on the theory of similitude. Gypsum, cement, and sandy mixes were used for materials. Seismic vibrations were excited by ultrasonic devices in the frequency range of 10-150 kHz.

● **6.3-11** Tzenov, L., **Vibrations of a system with joining connections,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-18, 1978, 129–132.

● **6.3-12** Kiricenko, A. I., **Analysis of the effects of the change of fundamental parameters on dynamic properties of multi-storey frame structures with one field,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-08, 1978, 53–60.

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In this paper, the results are presented of the effects of changes in structural parameters upon the dynamic properties expressed by the natural frequency spectrum. The analysis includes the variation of weight (mass) with elevation of a structure as well as the variation of element stiffnesses.

● 6.3-13 Gordon, L. A., Zabolotnaya, V. A. and Lyakhina, L. I., **The influence of pliability of support members and foundation of cooling towers upon seismic effort values,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-67, 1978, 501-507.

A method is presented for calculating the dynamic properties of concrete cooling towers in thermal and nuclear power plants. Calculations are based on the linear spectral theory which is the basis for the design standards adopted in the U.S.S.R. The cooling tower is represented as a smooth thin shell of revolution of variable thickness, and the support structure is idealized as a continuous linearly deformable foundation. Relationships for evaluation of pliability matrices are given, including colonnade pliability and pliability of the Winkler-type soil foundation. A numerical example illustrates the effect of foundation pliability on the meridional and latitudinal values.

● 6.3-14 Napetvaridze, Sh. G. and Chlaidze, N. Sh., **Stresses of arch dams under the three-dimensional seismic oscillation,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-51, 1978, 379-385.

The natural vibrations of an arch dam as a three-dimensional system and the stress state resulting from seismic motion are discussed. The finite element method is used for different brick element meshes. Various methods of accounting for the foundation flexibility of the dam and an option for the perimetric joint are considered. The 270 m high arch dam is being built in the Georgian S.S.R.

● 6.3-15 Borisov, V. V., **Calculation of natural vibration modes and frequencies of arch dams by collocation method,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-52, 1978, 387-393.

A method for calculating the natural vibration modes and frequencies of concrete arch dams using basic functions and the collocation method is developed. An arbitrary valley contour, the variation in thickness and curvature radius with dam height, and the added mass of water are taken into account. An ALGOL-60 computer program is developed and computation of a number of the dam characteristics is made.

● 6.3-16 Gran, C. S. and Yang, T. Y., **NASTRAN and SAP IV applications on the seismic response of column-supported cooling towers,** *Computers & Structures,* **8**, *6,* June 1978, 761-768.

Hyperboloidal reinforced concrete shells are modeled using orthotropic quadrilateral flat-plate finite elements. The supporting columns and top ring-beam are modeled by beam finite elements. Natural frequencies and corresponding mode shapes are found for several different tower configurations. Results for fixed-base shells are in close agreement with those determined using alternate methods of analysis. A cooling tower in the 1200 MW fossil fuel steam generating power plant at Paradise, Kentucky (Tennessee Valley Authority) is studied. Time-history responses of 30 sec to the north-south component of the 1940 El Centro earthquake are computed by modal superposition. Only the modes with one circumferential wave are excitable by horizontal motion. Contributions of the first three such modes are found using response spectrum analysis. The effect of viscous damping is considered. Two different structural programs, NASTRAN and SAP IV, are used at different points in the solution process. Advantages, disadvantages, and limitations in the present application are discussed.

6.3-17 Williams, F. W. and Howson, W. P., **Concise buckling, vibration and static analysis of structures which include stayed columns,** *International Journal of Mechanical Sciences,* **20**, *8,* 1978, 513-520.

The substitute columns previously used to determine exact elastic critical loads of individual stayed columns also can be used to determine the exact member equations of the columns. The equations can be used to economically represent the columns in stiffness matrix analyses. Subject to appropriate assumptions, such member equations apply to the classical buckling and vibration analyses emphasized in this study and to static analysis. A typical example indicates that the substitute columns can be used to determine the member equations with 6% of the effort involved in a standard substructure analysis of the original column, or 2% if the column is symmetric about its center. Moreover, the substitute columns tests offer helpful insights into the behavior of structures with stayed columns.

● 6.3-18 Healey, T. J. and Sozen, M. A., **Experimental study of the dynamic response of a ten-story reinforced concrete frame with a tall first story,** *UILU-ENG-78-2012, Structural Research Series No. 450,* Univ. of Illinois, Urbana, Illinois, Aug. 1978, 119.

This report documents the experimental work and presents the response data obtained from three earthquake simulation tests of a ten-story reinforced concrete frame. Changes in the dynamic properties of the test structure, such as apparent frequencies and equivalent damping, are

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discussed. Observed maximum lateral displacements are compared with those obtained from modal spectral analysis.

● **6.3-19** Kaveh, A., **Static and kinematic indeterminacy of skeletal structures,** *Iranian Journal of Science and Technology, 7, 1,* 1978, 37-45.

A general function is defined for representing the static or kinematic indeterminacy of different types of skeletal structures. An expansion process is described, and an intersection theorem is proved for the determination of the degree of static or kinematic indeterminacy of multimember and/or complex pattern skeletal structures.

● **6.3-20** Kratky, R. G. and Salvadori, M. G., **Strength and dynamic characteristics of mechanically jointed cast-iron water pipelines,** *Grant Report No. 3a,* Weidlinger Assoc., New York, June 1978, 44.

The purpose of this interim report is to generalize and complement a previous report (Abstract No. 6.3-43, *AJEE,* Vol. 7) and to obtain the elastic and dynamic characteristics of mechanical joints with rubber gaskets and cast-iron pipes.

● **6.3-21** Wang, L. R.-L., **Vibration frequencies of buried pipelines,** *SVBDUPS Project Report No. 2R,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, 1978, 42.

This paper examines the fundamental dynamics of buried pipelines in order to determine their seismic vulnerability. The determination of fundamental frequencies of continuously elastic-supported straight pipelines subjected to axial, torsional, and flexural motions is discussed. Various boundary conditions, which can represent an actual structure, are considered. Using a finite element and consistent mass approach, the matrix formulation of buried pipelines is developed.

● **6.3-22** As'kov, V. L., Davidenko, N. D. and Monahenko, D. V., **Method for investigating seismic stress state of arch dams on physical models,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-37, 1978, 295-300.

A method is described for the evaluation of a physical model of the stress-strain state of an arch dam subjected to a seismic load prescribed by an earthquake accelerogram. The problem is presented in a linear formulation. The method includes linear modeling, a pulse technique for model testing, and numerical programs for scaling and stress analysis. The method is applied to the arch dam of the Inguri hydroelectric power plant in the U.S.S.R.

● **6.3-23** Karadogan, H. F., **Effects of P-Δ moments and rotatory inertias on the behavior of building structures,** *Stability of Structures under Static and Dynamic Loads,* Proceedings of International Colloquium, Washington, D.C., May 17-19, 1977, American Society of Civil Engineers, New York, 1977, 74-94.

The fundamental periods and hence the response of structural systems can be considerably affected by the second-order effect of axial loads. In order to make a decision about the order of importance and the necessity of using second-order analysis, the coefficient C can be used as a criterion. C may be either greater or less than unity and from a structural engineering point of view both cases are important.

Because of the simplicity of the proposed method, instead of a static analysis of structures subjected to lateral loads which are not static but are essentially dynamic, a dynamic analysis can be easily carried out by taking into account the P-Δ effect. The large deflections and vibrations of a structural system can be controlled using the procedure outlined by means of a flow chart. The second-order analysis is applicable to any type of structural system which has a similarity between buckling and free vibration mode shapes and which is subjected to lateral loads. Since it is a general method for static and dynamic loads and does not necessitate computer usage nor any kind of iteration either for axial loads or displacements, the method is suitable for practical applications and for codes.

● **6.3-24** Luz, E., **A mechanical model to calculate vibrations of multistory buildings,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 130, Nov. 1978, 1033-1040.

A model is developed for determining the mechanical properties of a multistory building as a one-dimensional continuum. The model is suitable for convenient calculation of natural frequencies and modes of the coupled bending-torsion movements of multistory buildings. The exact determination of these coupled movements is a basic requirement of every dynamic or seismic calculation of multistory construction. The shape of the building may be arbitrary, but its length and width should not substantially exceed its height. The model permits the calculation of the influence of given arbitrary translations and rotation at the base of the building on its movement as seismic loads are determined. A model of this type seems to be a precondition for studying interactions between soil and buildings. The continuous structure of the model might allow the optimization of a multistory building with respect to dynamic or seismic loads or the determination of the influence of stochastic excitations in a comparatively easy manner. Damping properties may be included in the model, if necessary.

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● 6.3-25 Toki, K. and Sato, T., **Detection of dynamic properties of structural system by time series analysis** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 127, Nov. 1978, 1009-1016.

This paper concerns the detection of the natural period and the damping factor from the response of a linear structural system to random excitation, such as wind, traffic vibration, and microtremors. The nonstationary time series is defined by an extension of a stationary time series. The analytical procedure is based on the two-stage least-squares method for estimating the parameters of an autoregressive moving average process. In the first least-squares stage, the autoregressive parameters are estimated from the sequence of data by solving the Yule-Walker equation and by using the concept of maximum entropy proposed by Burg. The stationary time series is subjected to an investigation of the effect of sampling data length on the accuracy of the estimated dynamic properties of structural systems. Used for the analyses is the discrete time series data of the response of a linear system excited by a white noise. The procedure also is applied to multidegree-of-freedom systems. For illustrative purposes, two and five degree-of-freedom systems are considered.

● 6.3-26 Saionji, S. *et al.*, **Stress at the bend section of underground pipeline during earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 117, Nov. 1978, 929-936.

In curved and expansion joint sections of underground pipelines, thrust blocks have usually been provided to support the pipes. However, it is not always convenient to lay pipelines in a city area because of the number of blocks needed to support the many curved sections. These must be used because of the limited availability of land. This paper studies the stress behavior during an earthquake at the curved section of an underground pipeline not supported by a thrust block. The analysis was conducted using two methods: (1) displacement of the ground is given by an S-wave (sine wave) and (2) an actual earthquake wave is applied to the base rock foundation.

An analysis was made of pipelines of several shapes (different intersection angles and radii). It was found that the stress concentration occurs at the curved section of the pipelines. The value of the maximum tensile stress at the curved section varies with the direction of seismic wave propagation and with the intersection angle of the pipe curvature. Bending stress at the curved section is at a maximum for a pipeline with a 60-degree intersection angle. Maximum tensile stress and bending stress calculated using method (2) are 0.6 to 0.75 times and 0.9 to 1.15 times those of method (1), respectively.

● 6.3-27 Hamada, M., Yokoyama, M. and Sugihara, Y., **A study on the dynamic stresses of an underground tank by earthquake observation and numerical analysis** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 121, Nov. 1978, 961-968.

The authors have observed earthquake motions of an underground tank with a cylindrical shape, 24 m in diameter and 10.3 m in depth. The dynamic strains were measured on the side wall, and the accelerations and the displacements were observed on the ground surface and on the tank. The frequency characteristics of the acceleration in the tank are almost the same as those of the ground except that frequencies higher than 2.5 Hz occur in the spectra of the accelerations on the tank and the acceleration amplitudes on the tank are smaller than those on the ground surface. These results indicate that the influence of the natural vibration of the tank itself can be neglected in the dynamic behavior of the tank and ground. The circumferential strains on the inner surface of the side wall have close correlations with the relative displacements, namely, the strains of the ground.

A method of analysis for the stresses of an underground tank is proposed. The tank is modeled as an axisymmetric structure supported by an elastic foundation of the ground. The deformation of the tank is calculated from a statical equilibrium equation in which the displacements of the ground are forced to the tank using a ground spring. The analyzed strains of the tank agree qualitatively and quantitatively with the observed strains. From nondimensional parametric analyses, the following results were obtained. (1) The strains of the underground tank during earthquakes are smaller than almost 10% of those of the ground. (2) When a tank is shallow and the side wall is not connected to the base, the circumferential stress of the side wall is dominant. This is caused by the strains in the horizontal plane of the ground. When the tank is deep and the side wall is fixed or hinged to the base, the shear stress and the bending stress are dominant. This is caused by the shear strain in the vertical plane of the ground.

● 6.3-28 Takewaki, N. *et al.*, **Dynamic response analysis and earthquake observation of in-ground tank** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 124, Nov. 1978, 985-992.

The earthquake observation of an embedded LNG tank has been carried out at Sodegaura in Chiba Prefecture. The dimensions of the tanks, which have been either under operation or under construction, are 60 to 70 m in diameter and 20 to 30 m below the ground level.

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Fifteen earthquake waves were recorded from Nov. 1976 to Jan. 1978. From the dynamic response analysis of the tank using the records, the following results were obtained. (1) The predominant periods at the site of the tank are 0.55, 0.26, 0.16, and 0.12 sec from the first mode to the fourth mode, respectively. (2) The behavior of the tank during earthquakes coincides with the ground motions in the range of frequency under 2 Hz. In the range of frequency higher than 2 Hz, the tank behavior nearly coincides. However, at the frequency of 3.3 Hz, the first vibration mode of the side wall of the tank predominates. (3) For the dynamic response analysis of such tanks, an analytical method assuming expansion of the displacements, strains, stresses, and forces by the Fourier series is useful. (4) Semi-infinite elements can be used for the boundary condition at the side of the analytical model.

● 6.3-29 Yamada, T., **Structural analysis of the rectangular plane frame with aseismic walls** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 110, Nov. 1978, 873–880.

A finite element approach for the analysis of rectangular plane frames with shear walls is presented. The structure is assumed to be composed of linearly elastic materials. The effect of shearing deformations of joint panels such as connections of beams to columns is taken into account. The frames restraining the walls are replaced with linear prismatic members. The effect of their sectional dimensions such as width or depth are taken into account. The four edge displacements of the walls must be compatible with those of the restraining frames at the connection boundaries. The compatibility condition is satisfied for all displacement; i.e., thrust, bending, and shearing. The shear wall model is a rectangular finite element. The element has sixteen generalized displacements, two translations, and two rotations at each corner. Shape functions selected for this element are expressed by Hermitian polynomials. Since adjacent element edges rotate independently at each corner, the shear strain is not zero at four points on the element. This fact is of physical importance considering the characteristics of shear deformations. Construction of a stiffness matrix for a shear wall and the combination of beam-column stiffness matrices are described.

● 6.3-30 Kawai, T. and Kondou, K., **Shakedown analysis of engineering structures by using new discrete elements,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 149–156.

A method of shakedown analysis is given for engineering structures such as nuclear reactor vessels under combined fluctuating mechanical and thermal loadings and tall buildings subjected to earthquake motion. A family of new discrete elements is used. These discrete models consist of rigid bodies with two types of springs which connect elements to each other and are distributed over the boundary surfaces among the elements. Spatial movement of each element can be characterized by the displacement of the corresponding centroid so that, in any structural analysis, the size of the stiffness matrices of these elements never exceeds 6 x 6. Shakedown or incremental collapse load analysis of simple framed structures is illustrated by using the standard incremental load procedure.

● 6.3-31 Losaberidze, A. A. and Papuashvili, Z. V., **Application of the method of finite crossing bands for the spatial dynamic calculation of the combined buildings,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 195–200.

The dynamics of structures having complicated spatial configurations and variable rigidity along the height are considered. A discrete dynamic calculation diagram is suggested. The building is considered as a system of rows of mutually crossed vertical and horizontal elements.

● 6.3-32 Honma, T. *et al.,* **Seismic response control of piping supported by mechanical snubber,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 173–180.

A seismic analysis method for piping supported by mechanical snubbers constructed from mechanical elements is developed and applied to determine the smaller value of seismic response. Mechanical snubbers have spring-type and inertia mass-type characteristics. The rotational inertia of the flywheel of the mechanical snubbers does not become the shaking inertial force, so that the participation factors of piping supported by the mechanical snubbers change with the rotational inertia. Since the participation factor of piping is smaller for the spring-type than for the inertia mass-type mechanical snubber, use of the inertia mass-type is better for seismic-resistant design.

● 6.3-33 Mikluchin, P. T., **Basic principles of structural mechanics of tall masonry buildings,** *North American Masonry Conference Proceedings,* Paper No. 93, 20. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper discusses the unique structural performance of tall masonry buildings. A uniform analytical approach to three-dimensional structural analysis of tall masonry bearing wall buildings is presented. An investigation of the distribution of stresses, strains, and deformations resulting from static loads is carried out and the results are used as a basis for a dynamic analysis. Static and dynamic stability problems are discussed. Dynamic problems associated with the distribution of stress and strain in masonry structures subjected to wind and seismic forces are outlined. The

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necessity of a dynamic approach for the consideration of wind-induced vibrations is mentioned. Simultaneous axial and flexural-torsional vibrations and their interdependence are discussed. Structural integrity and progressive collapse are considered and the possible use of a limit states design approach is discussed.

● 6.3-34 Medearis, K., **An investigation of the dynamic response of the Park Lane Towers to earthquake loadings,** *North American Masonry Conference Proceedings,* Paper No. 51, 16. (For a full bibliographic citation, see Abstract 1.2-12.)

The Park Lane Towers complex, located in Denver, Colorado, consists of four highrise towers. Each tower is approximately 206 ft high, with 20 levels and a two-level penthouse above ground. These highrise structures are unique because of their predominantly reinforced masonry construction. To learn more about the dynamic response of such structures to earthquake loadings, the Colorado Masonry Inst. sponsored an applied research study of the towers. Modern, computer-oriented analysis techniques, whereby mathematical models of the structures were subjected to earthquake ground motion time histories, were utilized. Three earthquake time histories were used. Two time histories had motions corresponding to a Richter magnitude of about 5.6, and the third time history, magnitude 7. The former are appropriate for the Denver area, while the latter relates to more severe seismic locations such as southern California. The magnitude 7 earthquake was utilized to determine how the towers would respond to ground motions much larger than anticipated in the design. This paper describes the dynamic response studies.

● 6.3-35 Hibbert, J. H., **Synthesis of lumped-parameter vibrating systems in which elemental stiffness may be varied,** *Journal of Sound and Vibration,* **61**, *2,* Nov. 22, 1978, 161-167.

This paper describes a method of synthesizing the stiffness of the elastic elements in linear lumped-parameter vibrating systems so that one mode has a prescribed natural frequency and mode shape. It is shown that, although in many cases a unique solution to the problem does not exist, a least squares solution can readily be evaluated and used as a basis for obtaining a general solution in the form of a linear combination of a number of linearly independent vectors. This type solution is found to be particularly convenient when additional optimization is to be carried out on the system being considered. The use of the method is illustrated by means of two numerical examples.

● 6.3-36 Takahashi, K. and Chishaki, T., **Free vibrations of plate structures with intermediate frames,** *Journal of Sound and Vibration,* **61**, *1,* Nov. 8, 1978, 79-99.

A method is proposed for the vibration analysis of a composite structure comprising a plate and frames. This method takes into account the effect of the rigidity of the beams or columns in the frames, which is incorporated in terms of restraining forces acting on the plate or beams in such a way that the continuity of deformation between the plate and frames at the intermediate supporting beams or columns is preserved. The resulting compatibility equations and boundary conditions of the plate and beams give the desired natural frequency equations. A unidirectionally continuous rectangular plate on a flexible simple beam, a unidirectionally continuous rectangular plate on a rigid support, and a rectangular plate on an intermediate frame are treated to illustrate application of the method.

● 6.3-37 Sethna, P. R. and Bajaj, A. K., **Bifurcations in dynamical systems with internal resonance,** *Journal of Applied Mechanics, ASME,* **45**, *4,* Dec. 1978, 895-902.

Dynamic systems with quadratic nonlinearities exhibiting internal resonance under periodic excitations are studied. Two types of transition from stable to unstable motions are shown to occur. One type is shown to be associated with jump phenomena while the other is shown to be associated with Hopf bifurcations of the averaged system of equations. In the latter case, the motions are shown to be amplitude modulated motions at the excitation frequency with the amplitude of modulation determined by the motion of a point on a torus.

● 6.3-38 Jauregui Toledo, H., **Comments about the free cantilever type bridge,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14**, Dec. 1978, 245-254.

This report summarizes the characteristics of a free cantilever-type bridge and the flexural analysis procedure and the construction technique used.

● 6.3-39 Marjanishvili, M. A., Chanukvadze, G. Sh. and Mikabadze, Y. G., **Constructive reliability of many-storeyed buildings with a stiff core under the seismic influence,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 189-193.

● 6.3-40 Lee, D. M. and Medland, I. C., **Base isolation—an historical development, and the influence of higher mode responses,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11**, *4,* Dec. 1978, 219-233.

In this paper, the evolution of a technique for protecting a structure from earthquake forces is traced. The most effective form, the base isolation system, is compared to other currently available techniques. The influence of higher mode effects in base-isolated multistory structures is

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investigated and shown to be of considerable significance in determining the shear forces in the upper levels of a structure. Because of these higher mode effects, the responses of appendages on isolated structures, while still less than those for appendages on unisolated structures, can be significantly larger than previous one-dimensional analyses had suggested. A standard set of distributions for interstory shear in a multistory structure is presented with each distribution defined by a parameter varying from zero to unity.

● 6.3-41 Dempsey, K. M., **On the earthquake generated response of torsionally unbalanced buildings,** *Report 177,* Dept. of Civil Engineering, Univ. of Auckland, New Zealand, May 31, 1978, 83.

The coupled lateral-torsional response of torsionally unbalanced "shear" structures to horizontally directed earthquake excitation is investigated. The study is confined to analytical models that have linearly elastic, viscously damped responses. The investigation involves three separate analyses: (1) In a preliminary study, the earthquake response of an asymmetric, single-story building model is analyzed, and general expressions are derived for the location of the center of stiffness and the orientation of the principal axes. (2) An analysis is made of the coupled lateral-torsional response of a partially symmetric, single-story building model to a single component of earthquake excitation. A modal solution of the two equations of motion is developed, and a general criterion is derived for the existence of full modal coupling. By employing the design spectrum concept, together with conservative rules for the combination of modal maxima, analytical results in dimensionless form are evaluated for an equivalent static shear and an equivalent static torque. The combination expressions are then modified to include an allowance for modal coupling before the final results are computed and tabulated. The results substantiate previous findings, which have pointed to a possible link between strong modal coupling and severely coupled lateral and torsional responses. In particular, the results indicate that nominally symmetric buildings which exhibit strong modal coupling may respond more strongly in torsion than has hitherto been recognized by most building codes. This effect has not in the past been quantified in analytical terms. Although the results have practical applications in design, the analysis concerns itself primarily with the determination of realistic estimates for the dimensionless response quantities, and no attempt is made to derive design rules. (3) The partially symmetric, single-story model is extended to a special class of partially symmetric, multistory "shear" buildings. The results for the single-story model and those for the continuous multistory model are similar.

● 6.3-42 Joseph, M. G. and Radhakrishnan, R., **Influence of earthquake patterns on mode contribution,** *Bulletin of the Indian Society of Earthquake Technology,* **15,** *1 & 2,* Mar.-June 1978, 14-19.

Results of an analytical study made on the intermodal response behavior of four structures subject to earthquakes of five different patterns are presented.

● 6.3-43 Gupchup, V. N. *et al.,* **Seismic analysis of a large span aircraft hangar,** *Bulletin of the Indian Society of Earthquake Technology,* **15,** *1 & 2,* Mar.-June 1978, 1-7.

This paper presents the seismic analysis of a typical aircraft hangar structure being constructed at Bombay for Indian Airlines Corp. The main supporting structure has a very heavy mass at the roof level and a few large size columns of height to depth ratio ranging between 2.5 to 4.0. The main objective of this investigation is to study the effect, on the magnitude of seismic forces, of (1) large variation in masses at various floor levels and (2) inclusion of shear deformation in columns and large moment of inertia of beams in the column region. The results obtained by modal analysis on the basis of recommendations of IS: 1893-1975, are compared for the two cases (a) considering the above referred two effects and (b) neglecting the two effects.

● 6.3-44 Engels, R. C. and Meirovitch, L., **Response of periodic structures by modal analysis,** *Journal of Sound and Vibration,* **56,** *4,* Feb. 22, 1978, 481-493.

A periodic structure is a structure consisting of identical substructures, coupled together in identical ways to form the complete system. The undamped response of such a system is derived by using a modal analysis technique. The procedure allows for arbitrary loads and takes full advantage of the periodic properties of the structure. The algorithm is based on a technique previously developed by the authors.

● 6.3-45 Ceccoli, C. and Merli, M., **A simplified study of the state of deformation of shear walls with openings–definition of equivalent frame** (Alti edifici: lo studio semplificato dello stato di deformazione della parete irrigidente con fori - definizione di trave equivalente, in Italian), *Giornale del Genio Civile,* **116,** *10-12,* Oct.-Dec. 1978, 359-375.

6.4 Deterministic Dynamic Behavior of Linear Structures

● 6.4-1 Srinivasan, R. S. and Munaswamy, K., **Dynamic response of skew bridge decks,** *Earthquake Engineering and Structural Dynamics,* **6,** *2,* Mar.-Apr. 1978, 139-156.

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The dynamic response of a skew bridge deck is investigated by treating it as an orthotropic plate and using the finite strip method. Employing the normal mode method, the response of the deck to a moving force is calculated. Williams' method is used to accelerate the convergence of the solution. Numerical work is presented for different skew angles and speed ranges, and the history curves and the maximum amplification spectra for deflection and bending moment are given.

● 6.4-2 Birss, G. R., **The elastic behaviour of earthquake resistant reinforced concrete interior beam-column joints,** *78-13,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1978, 117.

This report examines a theoretical and experimental study of the behavior of interior reinforced concrete beam-column joints under simulated earthquake loading. An experimental program investigated the performance of two beam-column joint subassemblages subjected to static cyclic loading within elastic limits. The post-elastic behavior of the two test units was then examined by testing to failure.

A theoretical method for analysis of the joint shear resisting mechanisms is reviewed, and analyses of prototype beam-column joints are reported. The results are then compared with those obtained from the test units. The design provides a satisfactory and conservative estimate of the joint shear reinforcement required in an elastic beam-column joint. The failure of the joints in the test units verified that joint response to inelastic seismic loads would have been unsatisfactory.

● 6.4-3 Skoko, D., **Structure response to earthquake analysis done by A. Mohorovicic in 1910,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-01, 1978, 1-5.

● 6.4-4 Babu, K. G., **Response of partially prestressed members to repeated overloads,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-43, 1978, 319-326.

The methods available for the prediction of the response of partially prestressed members to repeated loading are presented. Based on an experimental investigation covering the entire range of partial prestressing, a method is proposed for the prediction of the unloading-reloading response of partially prestressed members with any degree of prestress. The effect of repeated loading and overloading on the various limit-states in partially prestressed concrete members is reported. It is observed that the previous load history has no noticeable effect on the behavior of these members during subsequent higher static loads.

● 6.4-5 Becker, J. M. *et al.,* **The seismic response of precast concrete panel buildings considering connection behavior,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-35, 1978, 257-264.

This paper examines the preliminary results of research of the seismic response of large-panel precast concrete construction typical of that used in the U.S. Seismic response is modeled using finite element procedures and an explicit time-step integration scheme. The seismic-resistant elements of a cross-wall system are isolated to study the possible role of connection regions in seismic response. Results are presented that show the effects associated with rocking-type motion and connection slippage in an isolated cross-wall and with the coupling action of vertical connections in a composite wall.

● 6.4-6 Velkov, M. *et al.,* **Theoretical and experimental study of the precast large panel structural system "Spuz,"** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-36, 1978, 265-270.

This paper considers the methods and results of a long and complex research project on the behavior of structures constructed by using a precast large-panel structural system known as "Spuz." By a theoretical investigation of mathematical models of structures having similar designs but different numbers of stories (5, 7 and 9) and a preliminary analysis using defined seismic-resistant design criteria, corrections in the joint system were made, and experimental investigations of full-scale joints under quasi-static cyclic loads carried out. A full-scale dynamic forced-vibration test was correlated with the mathematical model for elastic behavior for a representative seven-story building constructed by the system.

6.4-7 Lee, T. H. and Chuang, A. S., **Seismic response of gas-cooled fast breeder reactor core structural assembly via modal synthesis,** *Nuclear Engineering and Design,* **49,** *3,* Sept. 1978, 269-277.

An investigation has been conducted to determine theoretically the dynamic response of the GCFR core support structural assembly when subjected to boundary excitation from seismic disturbances. The system analyzed consists of a thick grid plate to which many core elements are attached vertically. The dynamic problem was solved by synthesizing component modes of two substructures and treating them as continuous subsystems. The investigation is of practical significance in that the radial responses of the core elements in axisymmetric motions cause a reactivity change of the core; therefore an accurate assessment of the dynamic response of the system is important to the core and core support structure design. Numerical system modal data and time-history response results are presented.

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● 6.4-8 Nath, B. and Soh, C. H., **Transverse seismic response analysis of offshore pipelines in proximity to the sea-bed**, *Earthquake Engineering and Structural Dynamics*, **6**, *6*, Nov.-Dec. 1978, 569-583.

Both harmonic and seismic responses of several idealized offshore oil pipelines near the sea-bed are studied in this paper by using a digital computer algorithm. In this algorithm, spatial discretization is based on finite elements with nodal lumped masses, while a step-by-step explicit forward integration scheme is used for processing in the time domain. A study of the basic system parameters shows that pipe response to a horizontal transverse ground excitation is affected mainly by the clearance between the pipe and the sea-bed, pipe geometry, and the end-restraints. Results also show that the overall effect of nonlinear pressure drag is not substantial. Relevant aspects of fluid dynamics affecting system response and the possible effects of marine growth on the pipe surface and the structural/chemical degradation of the pipe coating are also discussed.

● 6.4-9 Tanaka, H. *et al.*, **Earthquake response analysis of a 1-bay 2-story steel frame by computer actuator on-line system** (in Japanese), *Seisan-Kenkyu*, **30**, *4*, 1978, 17-20.

● 6.4-10 Cheung, Y. K. and Swaddiwudhipong, S., **Analysis of frame shear wall structures using finite strip elements**, *Proceedings, The Institution of Civil Engineers*, Part 2, **65**, Sept. 1978, 517-535.

The behavior of a coupled frame shear wall structure under a static loading system is studied using the finite strip method. The solid walls in the structure are modeled from ordinary strip elements; the connecting frames and spandrel beams are treated both as a continuous shear connection medium, or directly as discrete beams spanned between strips (walls) and/or line elements (columns). The accuracy and versatility of the proposed method are demonstrated by numerical examples.

● 6.4-11 Nelson, I. and Weidlinger, P., **Dynamic seismic analysis of long segmented lifelines**, *Grant Report No. 10*, Weidlinger Assoc., New York, Nov. 1978, 29.

A long straight segmented pipe, with each link attached to the ground by a spring and a dashpot, is subjected to incoherent ground motion caused by a phase delay. The equations describing the axial response of the system are developed. Modal decomposition is used and closed-form expressions are given for the natural frequencies and mode shapes. Examples are given showing the center joint displacement time history when the lifeline is subjected to earthquake loading. Spectral techniques can be used to bound the motion with the interference response (IR) spectrum. This spectrum is the maximum difference in motion (response) of two adjacent points which are excited by a difference in ground input. The IR spectrum is a useful tool in the dynamic analysis of lifelines over a broad range of parameters.

● 6.4-12 Nishio, N., Ukaji, T. and Tsukamoto, K., **Observation of dynamic behavior of underground pipelines during earthquakes** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 116, Nov. 1978, 921-928.

Since Oct. 1972, the authors have conducted earthquake observations on underground pipelines at three sites—Yokohama, Soka, and Omori. After examining the records obtained, several features of the behavior of pipelines have been determined. Of most importance is that maximum earthquake acceleration is not necessarily the decisive factor in determining pipeline response but that frequency characteristics of earthquakes and vibration characteristics of the ground at the site are also important factors. For some cases, the strain of the pipeline is induced by long-period ground motion with very low acceleration and this strain is almost equal to the strain induced by the maximum acceleration portion of an earthquake. The axial strain was always less than the bending strain at the straight part of the pipeline.

● 6.4-13 Kogarumai, M., Hojo, S. and Iwamoto, T., **Observations of dynamic behavior of anti-earthquake ductile pipes in water-main for supply to water purification yard at Hakusan, Hachinohe City during earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 115, Nov. 1978, 913-920.

Water distribution pipes in the Hakusan water purification yard, Hachinohe City, constructed in May 1975, were designed for seismic safety. To confirm the safety of these pipes, observations have been carried out on the behavior of the ductile pipes and the surrounding ground during earthquakes beginning in May 1975. The present report summarizes the results of analysis of the records obtained until June 1978. Thirty-seven earthquakes were recorded. The observation equipment consists of a seismograph and a strain gauge for the ground, an accelerometer and a strain gauge for the pipe, and an expansion-contraction gauge at the joint. The equipment can measure motions simultaneously at many points. From the calculated and the observed values based on the shear wave propagation theory, the ground was classified into model criteria. With respect to the predominant period, it was found that intensive seismic record results, a microtremor value, and a calculated value showed good agreement. Ground acceleration that was related with epicentral distance and magnitude agreed well with Katayama's formula. Amplitude that was related with epicentral distance agreed well with Kanai's formula. Distortion of the ground was dependent upon velocity and acceleration. The strain for the pipe and the expansion and contraction of the joint is given by the strain for the earth. Almost all strains initiated in the pipe were offset by expansion and contraction at the joint.

● **6.4-14** 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 II: general analysis of one-story single-span shear walls)**, *Transactions of the Architectural Institute of Japan, 274,* Dec. 1978, 75-83.

● **6.4-15** Yoshimura, K. and Kikuchi, K., **Static and dynamic analyses of a R/C building damaged during the Oita earthquake of April 21, 1975 (in Japanese)**, *Transactions of the Architectural Institute of Japan, 274,* Dec. 1978, 43-53.

The results are discussed of analytical studies of a reinforced concrete hotel building which was damaged beyond repair during the Oita earthquake of Apr. 21, 1975. The analysis is based on an idealization of the damaged building as a mechanical model. Linear static and dynamic responses of the idealized structure when subjected to lateral motions coupled with torsional motion are studied, and the influence of the torsional motion on the elastic response is investigated. The results of these analyses may be summarized as follows: (1) The ground motion of the NS component of the earthquake was quite severe at the site of the hotel building; (2) The maximum base shear in the torsionally coupled system is less than in the corresponding uncoupled system; (3) The effects of torsional motion on horizontal deflection and the stresses of the building are not negligible; (4) The equivalent lateral force distribution for static analysis which is specified in the Uniform Building Code is more reasonable than that of the current Japanese Building Standard Law for this building; and (5) It is possible to evaluate the rigidity of the reinforced concrete shear walls by a simple analysis.

● **6.4-16** Strenkowski, J. and Pilkey, W., **Transient response of continuous elastic structures with viscous damping**, *Journal of Applied Mechanics, ASME,* **45**, *4,* Dec. 1978, 877-882.

A comprehensive theory is presented for the dynamic response of continuous structural members with viscous damping using a modal analysis. The theoretical development provides a concise set of formulas that may be used for any structural member for which the equations of motion are known. These formulas are appropriate for both self-adjoint and nonself-adjoint systems of equations, which may include viscous damping, nonhomogeneous boundary and in-span conditions, and arbitrary forcing functions. The axisymmetric transient response of a thick elastic cylindrical shell subjected to displacement boundary conditions is included to demonstrate the usefulness of the general formulation in uncoupling the response of complex structural members.

● **6.4-17** Lee, D. M. and Medland, I. C., **Estimation of base isolated structure responses**, *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11**, *4,* Dec. 1978, 234-244.

The dynamic responses are studied of a set of elastic six-story shear structures mounted on a bilinear hysteretic base isolation (B.I.) system and forced by a wide range of different types and strengths of actual and simulated earthquake records. For comparative purposes, responses to the same range of earthquakes are also computed for the same set of structures without the base isolation system. It is found that, for the B.I. system investigated, not only are the maximum shear forces in an isolated structure reduced to, on average, 0.2 of their values without B.I., but also that the maximum shear responses of isolated structures can be closely estimated from a wide variety of different parameters, selected from ground motion and elastic response spectrum data of the forcing earthquakes. Ninety-five percent confidence intervals are determined for the linear least squares regression relations between structural responses and earthquake parameters. For the isolation system considered, the maximum displacement across the isolation system during an earthquake is shown to be very closely correlated with the maximum structural shear force.

● **6.4-18** Cili, F., **Lateral load analysis of bearing wall structures** (Yigma yapilarin yatay yuklere gore hesabi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **6**, *22,* July 1978, 7-25.

In this study, a method of analysis for masonry structures subjected to seismic loads is explained. Material properties of earthquake-damaged masonry structures can be obtained from tested wall samples taken from the structures. Earthquake characteristics can be obtained from field observations and earthquake recordings. The response of a masonry structure is traced by using the abovementioned data. The correlation between the results of the analysis and the damage pattern of the structure will give useful information about the response of such structures during the earthquakes. This method of analysis can also be used in the design of masonry structures against earthquake loadings and for checking the lateral load capacity of existing masonry buildings.

6.5 Nondeterministic Dynamic Behavior of Linear Structures

● **6.5-1** Novak, M. and Hindy, A., **Dynamic response of buried pipelines**, *Sixth European Conference on Earth-*

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quake Engineering, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-71, 1978, 533–540.

Dynamic response of buried pipelines to earthquake excitation was investigated theoretically. The problem was formulated in terms of both deterministic and random vibration. Lateral and axial response were studied as well as seismic excitation traveling along a pipe under various angles of incidence. An extensive parametric study was conducted to identify the main factors affecting the response.

● **6.5-2** Spanos, P.-T. D., **Non-stationary random vibration of a linear structure,** *International Journal of Solids and Structures,* **14,** *10,* 1978, 861–867.

The nonstationary random vibration of a lightly damped linear structure subjected to white noise is considered. It is shown that the probability density function of the amplitude of the structural response can be approximated by a Rayleigh distribution. Analytical formulas for the time-dependent statistics of the amplitude are presented. The analytical results are compared with data obtained by numerical simulation.

● **6.5-3** Masri, S. F., **Response of a multidegree-of-freedom system to nonstationary random excitation,** *Journal of Applied Mechanics, ASME,* **45,** *3,* Sept. 1978, 649–656.

This paper presents an analytical study of the covariance kernels of a damped linear two degree-of-freedom system that is subjected to spatially correlated nonstationary stochastic excitation consisting of modulated white noise. A unit-step intensity function and an exponential function, resembling the envelope of a typical earthquake, are considered in conjunction with a propagating disturbance. Results of the analysis are used to determine the dependence of the peak transient mean-square response of the system on the uncoupled frequency ratios, mass ratios, wave propagation speed, shape of the intensity function, and system damping.

6.5-4 Ahmadi, G., **Earthquake response of linear continuous systems,** *Nuclear Engineering and Design,* **50,** *2,* Oct. 1978, 327–345.

The response of a general elastic linear continuous system to earthquake ground motion is considered. The existing stochastic models of earthquake strong motion are briefly reviewed. The general expressions for the power spectrum and correlation functions as well as the mean-square response are derived. It is shown that, for small damping coefficients, relatively simple results for the mean-square response functions could be obtained. The reliability of design is considered and the probability of barrier crossing is discussed. This paper is concluded by consideration of examples of earthquake responses of Euler-Bernoulli beams, nonuniform shear beams, and uniform plates.

6.6 Deterministic Dynamic Behavior of Nonlinear Structures

6.6-1 Jones, N. and Soares, C. G., **Higher modal dynamic plastic behavior of beams loaded impulsively,** *International Journal of Mechanical Sciences,* **20,** *3,* 1978, 135–147.

It was demonstrated in a previous study that the higher modal dynamic plastic response of beams may be a more efficient means of absorbing a given initial kinetic energy than a single modal response. This paper examines the higher modal dynamic plastic response of impulsively loaded, fully clamped beams using various rigid perfectly plastic theoretical procedures and a numerical elastic-plastic computer code.

● **6.6-2** Crespo da Silva, M. R. M., **Flexural-flexural oscillations of Beck's column subjected to a planar harmonic excitation,** *Journal of Sound and Vibration,* **60,** *1,* Sept. 8, 1978, 133–144.

The nonlinearly coupled flexural-flexural oscillations of a nonconservative column with two independent load parameters are investigated by analytical methods to determine the quantitative and the qualitative behavior of the response. The column is subjected to a planar periodic distributed load with a frequency near the eigenfrequency of its free bending oscillations. The analytical results are compared with those obtained by the numerical integration of a set of nonlinear differential equations obtained by the application of Galerkin's method to the original equations.

● **6.6-3** Matzen, V. C. and McNiven, H. D., **A mathematical model to predict the inelastic response of a steel frame: establishment of parameters from shaking table experiments,** *Earthquake Engineering and Structural Dynamics,* **6,** 2, Mar.-Apr. 1978, 203–219.

Experimental data is used to formulate a mathematical model to predict the nonlinear response of a single-story steel frame to an earthquake input. The process used is system identification. In experiments performed on a shaking table, the frame was subjected to two earthquake motions at several intensities. In each case, the frame underwent severe inelastic deformation. A computer program incorporating the concepts of system identification makes use of the recorded data to establish four parameters in a nonlinear mathematical model. When different amounts of data are used in the program, parameter sets are established which give the best model response for that

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amount of test data. These parameter sets reflect the way the properties of the structure change during the excitation. However, when the full durations of the different excitations are used, the parameter sets are almost identical. For each of these parameter sets, the correlation of the computed accelerations with the measured accelerations is excellent, and the shape of the computed displacement response compares very well with the measured response, although the permanent offset of the displacements is not computed exactly. Ways of overcoming this deficiency in the mathematical model are suggested.

● 6.6-4 Rossettos, J. N. and Perl, E., **On the damped vibratory response of curved viscoelastic beams,** *Journal of Sound and Vibration,* **58,** *4,* June 22, 1978, 535–544.

The damped forced vibratory response of viscoelastic beams with a small initial curvature is analyzed in order to explore the interaction of initial curvature with both extensional and shear deformation, since they provide energy dissipation mechanisms for the damped response. A nondimensional variational statement is developed which governs the problem of the forced vibratory response, including in-plane deformation, of slightly curved Timoshenko beams, and appropriate parameters are defined. In particular, initial rise and shear parameters are seen to play important roles in the results.

Numerical results are presented for the first three modes for both simple and clamped support conditions. In general, even a slight amount of initial curvature has a significant effect in decreasing the damped response for the first mode, and the actual effect is influenced strongly by the shear parameter. Initial curvature has a smaller influence on the higher modes. An understanding of when extensional or shear energy dissipation is dominant for certain ranges of values of the curvature and shear parameters is obtained by actual plots involving the appropriate form of energy dissipation. In general, extensional energy dissipation tends to dominate in the first mode for both support conditions, although the clamped beam tends to favor shear dissipation over a certain range of parameter values. The dominance of the shear mechanism, however, increases markedly for the higher modes for both support conditions.

● 6.6-5 Jain, A. K., Goel, S. C. and Hanson, R. D., **Inelastic response of restrained steel tubes,** *Journal of the Structural Division, ASCE,* **104,** *ST6,* Proc. Paper 13832, June 1978, 897–910.

Eighteen specimens made from 1 in. (25 mm) square tubes with welded gusset plates were tested under repeated axial loading. The length of the specimens varied from 20 in. to 54 in. (510 mm to 1370 mm), and their slenderness ratio varied from 30 to 160. The objective was to study the effects of connection flexural strength and stiffness, and change of member length on the hysteresis behavior. From the parametric study, it was concluded that the hysteresis behavior of flexurally restrained axial members is most influenced by the effective slenderness ratio. The results were compared with recent theoretical predictions and were, with some slight differences, in excellent agreement for members of larger slenderness ratio. It was also found that the maximum compressive load decreased and the member length increased with the number of cycles.

● 6.6-6 Prathuangsit, D., Goel, S. C. and Hanson, R. D., **Axial hysteresis behavior with end restraints,** *Journal of the Structural Division, ASCE,* **104,** *ST6,* Proc. Paper 13831, June 1978, 883–896.

A parametric study of axially loaded steel members with symmetrical rotational end springs (connections) was performed. The main parameters are the flexural strength of the connections, the effective slenderness ratio, and cross-sectional properties. The rotational end spring is a simulation of the end restraint resulting from the flexural rigidity of the connections of an axially loaded (bracing) member. The member with balanced strength connections, i.e., which forms plastic hinges simultaneously at midspan and at the ends, has more efficient compressive load and energy dissipation capacities than members of the same length and same cross-sectional properties with unbalanced strength connections. The hysteresis behavior of a balanced strength member can be represented adequately by that of a pin-connected member of the same cross section and same effective slenderness ratio.

● 6.6-7 Roeder, C. W. and Popov, E. P., **Cyclic shear yielding of wide-flange beams,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM4,* Proc. Paper 13920, Aug. 1978, 763–780.

The results of experiments with wide-flange steel beams subjected to cyclic shear yielding are described. Tests indicate that beams that yield in shear show stable behavior at large cyclic deflections and that they dissipate large amounts of energy. The significance of cross-sectional warping is shown, and the beneficial effect of cyclic diagonal tension fields is described. An analytical model is developed for predicting the inelastic behavior of shear yielding elements which shows good correlation with the test results. An application for accurate prediction of the global behavior of eccentrically braced steel frames subjected to cyclic loading characteristic of the problem in seismic-resistant design illustrates the usefulness of the analytical model.

● 6.6-8 Klingner, R. E. and Bertero, V. V., **Earthquake resistance of infilled frames,** *Journal of the Structural Division, ASCE,* **104,** *ST6,* Proc. Paper 13822, June 1978, 973–989.

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Quasistatic cyclic load tests were performed on one-third scale model subassemblages of the lower three stories of an eleven-story, three-bay frame with infills in the two outer bays. Frame members (particularly the columns) are designed for high rotational ductility and resistance to degradation under reversed cyclic shear loads. Gradual panel degradation is achieved using closely spaced infill reinforcement, and panel thickness is limited so that the infill cracking load is less than the available column shear resistance. Relatively simple, macroscopic mathematical models for predicting the experimentally observed bare and infilled frame behavior were developed. The infilled frame model gives excellent predictions of observed response. It is concluded that the procedure and the model can be used to predict the response of large, engineered infilled frame structures to severe lateral forces.

● **6.6-9** Huckelbridge, Jr., A. A. and Clough, R. W., **Seismic response of uplifting building frame,** *Journal of the Structural Division, ASCE,* **104,** *ST8,* Proc. Paper 13974, Aug. 1978, 1211–1229.

The response of a 9-story steel frame model tested on the Univ. of Calif., Berkeley, shaking table is compared to analytical predictions. The uplifting response is compared to the response for the same excitation with overturning anchorage provided, demonstrating a considerable reduction in the applied loading for the uplifting case. Application of the test results to a theoretical prototype frame indicates that a significant uplifting response would occur during a moderate, credible earthquake, although such a response is not indicated even by conservative building code seismic provisions. A rational consideration of the uplifting behavior is shown to be compatible with the concept of dual seismic loading criteria; these criteria are for a service loading that should produce no damage and a maximum credible loading that should not result in catastrophic failure. A design including a rationally planned uplifting capability should stand a much better chance of surviving a maximum credible earthquake in a functional condition.

● **6.6-10** Mote, S. H. and Chu, K.-H., **Cable trusses subjected to earthquakes,** *Journal of the Structural Division, ASCE,* **104,** *ST4,* Proc. Paper 13699, Apr. 1978, 667–680.

Earthquake responses of cable trusses, with the top cable curved up and the bottom cable curved down, and diagonal web members are the subject of this study. The trusses must have special features because the diagonals come in and out of action during vibration. An outline of nonlinear analysis of static and dynamic problems of elastic cable trusses is presented, and the results are compared with published examples. For limiting the degrees-of-freedom, only plane trusses with masses lumped at the joints are studied. An analysis of an example truss is presented. The truss is pretensioned so that it will have very small deflection under dead load, and so that there will be sufficient tension in the lower cable to stabilize the structure when the line load occupies the whole or half of the span. Deflections and member forces of the example truss subjected to vertical and horizontal (north-south) motions of the El Centro earthquake are given.

● **6.6-11** Heng, N. K., **Seismic behaviour of circular reinforced concrete bridge piers,** *78-14,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1978, 141.

The ductility demand of circularly reinforced concrete bridge piers is examined. A series of dynamic inelastic analyses were carried out to study the effect of earthquake types and the natural pier periods on the ductility demand of bridge piers. The effect of flexible foundations on the dynamic response was studied by different methods of modeling the foundation flexibility. Results from these studies are compared with the New Zealand Ministry of Works and Development (MWD) ductility requirement. Dynamic analyses were also carried out using a realistic model in which soil is replaced by an equivalent system of springs to determine the damping resulting from soil yielding. Static cyclic tests were carried out on two pier models; one was designed to MWD's requirements, and the other, which was highly stressed axially, had a transverse reinforcement in excess of the New Zealand Concrete Draft Code requirements. Results from these tests are compared with requirements specified by the MWD. The theoretical moment, calculated using a set of proposed stress-strain curves, is compared with an experimental value to ascertain its validity. Conclusions on the adequacy of the transverse reinforcement required by MWD's current practice and by the New Zealand Concrete Draft Code for a highly axially stressed pier are drawn.

● **6.6-12** Jury, R. D., **Seismic load demands on columns of reinforced concrete multistorey frames,** *78-12,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1978, 122.

In this report, the effects of earthquake motions on multistory reinforced concrete framed structures, designed to proposed New Zealand building code requirements, are examined. The unidirectional responses of two six-story, a twelve-story and an eighteen-story prototype open-frame structure, subjected to several earthquake motions, are examined using a dynamic analysis computer program. The pattern and sequence of hinge formation and the variation of certain critical design quantities during the inelastic response of the structures were examined. The differences between the behavior assumed in the design and the behavior exhibited in the dynamic analysis were investigated in each response. From the results of the dynamic analyses, an assessment is made of the proposed design

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procedure. Amendments to the dynamic analysis program are suggested, and areas for further study are proposed.

● **6.6-13** Bicanic, N. *et al.*, **Nonlinear seismic response of concrete gravity dams,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-55, 1978, 411–419.

A procedure for the nonlinear dynamic analysis of a concrete gravity dam subjected to earthquake excitation is presented. The procedure uses finite element spatial discretization and finite difference temporal discretization. The concrete is modeled as an elasto/viscoplastic material of which the proportional limit surface and failure surface are assumed to be strain rate dependent. Material properties were defined by experiments conducted under strain rates typical of earthquake excitation. The procedure is demonstrated by a seismic analysis of the Koyna Dam.

● **6.6-14** Fajfar, P. and Zele, B., **Spatial seismic effects in multistorey structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-10, 1978, 69–76.

An analysis of structures subjected to seismic forces acting independently in the direction of each of the main axes of the structure is recommended by most codes. A plane vibration is usually assumed; and in asymmetrical structures, the static effects of torsion are sometimes added. In the paper, a more accurate approach (a dynamic three-dimensional time history analysis with simultaneous actions of two horizontal earthquake components) and an approximative approach advocated by the codes are compared. It is shown that for complex multistory structures a three-dimensional vibration analysis should be used and that the response quantities caused by the independent action of two horizontal earthquake components should be combined using the square root of the sum of the squares method.

● **6.6-15** McNiven, H. D. and Stanton, J. F., **A model for predicting the nonlinear, flexural response of reinforced concrete members to seismic forces,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-37, 1978, 271–279.

A mathematical model is constructed for predicting the nonlinear cyclic behavior of reinforced concrete beams in flexure. The model accounts for the constitutive behavior of the steel and concrete and the interaction between the two materials. Since it is felt that the behavior of the reinforcing will predominate in the response, it is explored in detail in this paper. The model is constructed using system identification. The form of the model is after Menegotto and Pinto. The parameters are allowed to vary with strain. Predictions from the model match complicated experimental data extremely well.

● **6.6-16** Atalay, M. B., **A mathematical model for the seismic behavior of reinforced concrete critical regions as influenced by moment and shear,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-38, 1978, 281–288.

A mathematical model for analysis of the seismic behavior of reinforced concrete critical regions influenced by moment and shear is formulated. Through the use of the model, the inelastic cyclic force-displacement relationship of such critical regions corresponding to a given lateral displacement time history can be obtained. The form and parameters of the model were chosen to realistically reflect important characteristics affecting inelastic cyclic behavior. Empirical relationships are given for the numerical evaluation of the parameters of the model. Finally, the model is checked against experimental data.

● **6.6-17** Eisenberg, J. M. *et al.*, **Response and reliability of self-adjusting structures with disengaging elements during high-frequency and low-frequency earthquakes,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-06, 1978, 39–46.

● **6.6-18** Capecchi, D., Rega, G. and Vestroni, F., **Nonlinear dynamic analysis and ductility requirements of multidegree-of-freedom structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-09, 1978, 61–68.

The use of the ductility factor in the seismic analysis of multidegree-of-freedom structures depends upon the possibility of defining realistically the plastic mechanism of the structure during an earthquake. In this paper, ductility requirements of two shear models with different natural periods are examined. Stories are assumed to behave elastoplastically; the response is obtained by step-by-step integration of the equations of motion. Three distributions of story stiffnesses and two ground motions of different intensities are considered. The influence of different distributions of plastic deformations on the capability of the structures to withstand motions beyond the elastic range is analyzed.

● **6.6-19** Derecho, A. T. *et al.*, **Relative influence of selected structural parameters on the inelastic seismic response of isolated structural walls,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-26, 1978, 187–194.

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Results of a parametric study aimed at identifying the major variables affecting the dynamic inelastic response of isolated structural walls are presented. Among the parameters considered are the fundamental period, yield level, yield stiffness ratio, character of the hysteretic force-displacement loop (unloading and reloading stiffnesses), damping, stiffness taper, strength taper, and degree of base fixity. Of major interest was the influence of these parameters on the force and deformation requirements in the hinging region near the base of the wall. Results are presented as response envelopes showing the relative influence of the individual parameters on selected response quantities. A comparison of the relative effects of the selected parameters is included.

● **6.6-20** Pekau, O. A. and Gocevski, V., **Parametric investigation of non-linear shear wall structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-27, 1978, 195–202.

This paper examines the ductility requirements of coupled shear walls laterally loaded to collapse. Employing a simplified analysis, a series of coupled structures is investigated by means of a parametric scheme. Parameters related to the geometric stiffness properties of coupled systems are identified and the influence of certain building dimensions on a typical range of values is presented. Nonlinear behavior at collapse is studied for variation of the stiffness parameters, as well as for different coupling beams strengths.

● **6.6-21** Gocevski, V. and Pekau, O. A., **Moment-axial force interaction in coupled shear walls,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-28, 1978, 203–210.

The results of an investigation of the moment-axial force interaction in coupled shear walls subjected to lateral loading are described. The influence on the overall behavior of the structure of the yielding of the first wall at its base is examined. Structural response is expressed in terms of ductility requirements and load displacement relations for different assumptions for the postyielding moment-axial load behavior of the wall.

● **6.6-22** Iwan, W. D., **The earthquake response of strongly deteriorating systems including gravity effects,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-04, 1978, 23–30.

This paper presents a new model for the description of strongly deteriorating or degrading structural systems where gross crushing, spalling, and loss of material are important. First-order gravity effects are also included. Averaged inelastic response spectra are given for a nondegrading and a strongly degrading system subjected to an ensemble of earthquakes. The response is compared to that of a simple linear system. Factors affecting structural collapse are considered, and a maximum acceptable design level peak acceleration is determined for each structural system.

● **6.6-23** Erdik, M. O., **Nonlinear, lateral-torsional response of symmetric structures subjected to propagating ground motions,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-13, 1978, 93–100.

This study deals with the nonlinear, lateral-torsional response of three-dimensional, shear-beam-type structures subjected to nonsynchronous seismic excitation of the bases. After reviewing the linear behavior, nonlinear response spectra are presented for the total maximum column deformation and the component translational motions for various yield levels and rates of propagation. It is found that the maximum column deformation is generally less than that obtained by neglecting the propagating character of the ground motion. The physical reasons for this behavior are explained.

● **6.6-24** Borcia, I. S. and Sandi, H., **Analysis of oscillations of silo structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-65, 1978, 485–492.

This paper describes experimental and analytical research on the analysis of seismic oscillations of silo structures. The analytical work is based on a model that represents silos as vertical chain-like structures. The model considers the flexibility of the ground, main columns, cells and upper structure, and inertia resulting from the structure itself and from the padding (assuming total or partial, nonsymmetrical filling). The experimental work is based on recordings of low-in-density oscillations caused by microtremors. The recordings were carried out on silos in use. Quantitative results and conclusions concerning the design of silos are presented.

● **6.6-25** Braga, F. and Parducci, A., **Plastic deformations requested to R/C structures during strong earthquakes. Influence of the mechanical decay by taking into account the P-Δ effect,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-42, 1978, 311–318.

Using the principal records of the recent Friuli earthquakes, the response spectra of two types of buildings are examined. When considering elastoplastic behavior, it is important to take into account the P-Δ effect and the decay of the mechanical properties of structures as a result of violent earthquakes. An original decay scheme is adopted

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that can represent the behavior of reinforced concrete columns. Some general conclusions are reported concerning the seismic safety of the two types of buildings considered.

● 6.6-26 Juhasova, E., **Nonlinear seismic response of steel framed structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-09, 1978, 67–74.

The nonlinear seismic vibration of structures is discussed. Experimental results are presented of measurements of the nonlinear seismic harmonic response of steel frame models constructed of rectangular cross-sectional elements and of closed thin-walled profiles. A theoretical solution is derived for the systems. Only the nonlinearity of the damping forces is considered in the calculation.

● 6.6-27 Penzien, J., **Seismic analysis of multi-span reinforced concrete bridges,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-03, 1978, 19–28.

A brief description is presented of nonlinear mathematical modeling and analysis procedures for predicting the response of multi-span reinforced concrete bridges to strong seismic ground motions. The validity of these procedures is verified through a correlation of predicted response with the measured response of a model bridge structure subjected to simulated seismic motions using the Univ. of California, Berkeley, two-component shaking table. It is concluded that these theoretical procedures can be used effectively in developing improved seismic design criteria, and that they can be of great assistance in developing the design of an unusual structure.

● 6.6-28 Kelly, J. M. and Derham, C. J., **An anti-seismic isolation system for structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-07, 1978, 53–59.

This report describes the experimental and analytical results of a practical earthquake isolation system. The soft story isolation system is composed of elastic natural rubber bearings and a highly nonlinear energy-absorbing device, all placed beneath the base floor of the model structure. The bearings allow for lateral movement of the base of the model and are designed so that no adverse column P-Δ effects can occur. The energy-absorbing devices act as highly efficient dampers, and are based upon the two-way plastic torsion of steel bars.

For small earthquakes, the structure behaves as with a rigid foundation. For large earthquakes, the first mode period increases and equivalent first mode damping between 30% and 35% is produced. For destructive earthquakes, the isolation system typically reduces the response by over 50% of that of a conventional rigid foundation.

● 6.6-29 Zagajeski, S. W. and Bertero, V. V., **Hysteretic behavior of R/C columns subjected to high axial forces and cyclic shear forces,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-20, 1978, 159–166.

The results of an experimental study of the inelastic behavior of short R/C columns subjected to high axial loads of constant magnitude and cyclic shear forces are summarized. The program was developed to evaluate the soundness of recent design recommendations for seismic-resistant R/C columns. The influences of the magnitude of axial load, type of transverse reinforcement, and deformation history were studied. All columns developed their flexural capacity and experienced significant inelastic deformation before either a significant shear degradation or a brittle shear failure.

● 6.6-30 Ungureanu, N. and Negoita, Al., **Seismic effects on unsymmetrical structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-15, 1978, 109–116.

The paper deals with the effects of torsion on asymmetrical buildings with rigid cores. It is proposed that the torsion effects be repartitioned among the structural members by taking into account the torsion stiffness of the cores. The paper also outlines the effect of obliqueness; this effect leads simultaneously to a change in the direction of seismic loading along the height of the structure and to a change in the main stiffness ratio. Results are presented and discussed.

● 6.6-31 Nonaka, T., **Elastic-perfectly plastic behavior of a portal frame with variation in column axial forces,** *Journal of Structural Mechanics,* **6,** *1,* 1978, 61–84.

A theoretical study is made of the hysteretic behavior of a portal frame under constant gravity and variable horizontal loading. Special account is taken of the variation of axial forces in the columns, the model simulating the plastic interaction of the overall shearing and bending in tall rectangular frames and battened columns. The assumed elastic-perfectly plastic behavior of columns makes a mathematical formulation feasible, and a detailed examination is given of the cyclic alternate displacement loading with the P-Δ effect taken into consideration. This example clarifies characteristic features of repeated loading such as shakedown, incremental collapse, and alternating plasticity under the combined action of bending moment and axial force existing in a frame member.

● 6.6-32 Khozeimeh, K. and Toridis, T. G., **Models for inelastic response of beam-plate assemblages,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM5,* Proc. Paper 14057, Oct. 1978, 1001–1014.

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A simplified method to account for inelastic behavior in beam-plate assemblages is proposed. This numerical technique, which is easier to implement than other methods, eliminates the need for iterative steps required in similar methods based on the flow rule. In addition, two models for determining the progression of inelastic zones in beam- and plate-type elements are presented. Based on this procedure and models, the nonlinear responses of some typical structures subjected to static and dynamic loads are determined. Comparison of the solutions with theoretical and experimental results reported by other investigators demonstrates the validity of the techniques.

● **6.6-33** Mondkar, D. P. and Powell, G. H., **Evaluation of solution schemes for nonlinear structures,** *Computers & Structures,* 9, 3, Sept. 1978, 223–236.

This paper investigates solution schemes that can be implemented in general purpose computer codes for nonlinear finite element analysis. A very flexible solution strategy is discussed in which a variety of solution schemes can be implemented by specifying the values of certain solution control parameters. A number of nonlinear structures with diverse nonlinear characteristics are selected, and each is analyzed using different solution schemes. The results and solution efficiency then are compared to help select the most appropriate solution procedures for various types of nonlinear behavior.

● **6.6-34** Sachanski, S., **Earthquake resistance of precast structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-28, 1978, 223–230.

An analysis is presented of the seismic resistance of precast industrial structures subjected to the Vrancea earthquake of Mar. 4, 1977. Single-story and large panel structures are studied. The analysis includes the mathematical modeling of the structures, using strength and deformation characteristics of joints in the elastic and inelastic ranges, and the modeling of earthquake motions. The theoretical structural response is evaluated and compared with actual structural response during the earthquake.

● **6.6-35** Zamolo, M. and Anicic, D., **Seismic collapse of reinforced concrete pendulum columns,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-24, 1978, 191–198.

Structural assemblages representing jointly connected pendulum columns in prefabricated tall buildings are studied. The purpose of the experimental research is to evaluate the use of such columns in seismic areas. Reinforced concrete models (scale 1:2.5) were subjected to constant axial loads and to slowly alternating lateral loads applied to the column ends. Some previously unknown energy absorption and damping coefficient characteristics were determined.

● **6.6-36** Aristizabal-Ochoa, J. D. *et al.*, **Cyclic inelastic behavior of structural walls,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-29, 1978, 231–238.

The behavior of sixteen reinforced concrete wall specimens subjected to in-plane horizontal reversing loads is described. Each specimen was tested under static combinations of axial load, bending, and shear. Walls were 4.57 m (15 ft) high and 1.91 m (6 ft 3 in.) wide with 102 mm (4 in.) thick webs. Controlled variables included shape of the cross section, amount of flexural and shear reinforcement, confinement reinforcement in the boundary elements, concrete strength, vertical load, and lateral load history. In addition, two repaired specimens were tested. Effects of variables on overall behavior, strength, and deformation characteristics are described.

● **6.6-37** Turnsek, V. *et al.*, **The seismic resistance of stone-masonry walls and buildings,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-32, 1978, 255–262.

Insight into the seismic resistance of stone masonry buildings has been obtained by (1) an analysis of damage caused to such buildings by the medium-sized Kozjansko (Slovenia) earthquake of 1974 and the two strong earthquakes which hit the Friuli region in Italy and the Soca valley region in Slovenia in May and Sept. 1976 and (2) shaking table tests of stone masonry wall elements and of a model stone masonry building. The results of laboratory tests of the strengthening of stone masonry walls and buildings and methods developed for calculating the shear resistance of masonry buildings have been verified on actual buildings in the village of Lusevera in Friuli, an area where the two 1976 earthquakes were of a similarly strong intensity.

● **6.6-38** Paulay, T., Park, R. and Priestley, M. J. N., **Reinforced concrete beam-column joints under seismic actions,** *Journal of the American Concrete Institute,* **75**, *11*, Title No. 75-60, Nov. 1978, 585–593.

The behavior of interior beam-column joints under seismic actions is examined in detail. The existence of two shear-resisting mechanisms, one involving joint shear reinforcement and the other a linear concrete strut, is postulated. The effects of reversed cyclic loading on these mechanisms, in both the elastic and inelastic range of response, are discussed. Simple analytical models of behavior are presented. The detrimental effects are discussed of

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yield penetration into a joint upon longitudinal bar anchorage, and methods to overcome these effects are proposed.

6.6-39 Rezansoff, T., **Performance of lapped splices in reinforced concrete loaded beyond yielding of the steel,** *Canadian Journal of Civil Engineering,* 5, *4,* Dec. 1978, 489–496.

Eighteen beams designed to fail in the lap splice after yielding of the reinforcing steel were tested under either a single load application or low-cycle repeated loading. Splice lengths were varied from those well below code requirements up to approximately the lengths required by current codes and design methods. Performance was studied on the basis of the ductility exhibited prior to failure and the influence of the load cycling and the stress-strain characteristics of the reinforcing steel. No confinement (stirrups nor a spiral) was provided to the splice.

Comparison is made with common lap splice design methods. These assume that the beam will respond adequately and the splice will not fail prematurely if the splice length is made long enough to withstand a steel stress 25% above the normal yield strength of the reinforcing steel. It is noted that the higher than nominal yield stress and the strain hardening at relatively low strains for the grade 60 (nominal yield stress = 60 ksi) deformed reinforcing steel used in the study have detrimental effects on ductility. The possible weakness of using nominal yield strengths for the reinforcing steel with current design methods is emphasized.

● **6.6-40** Jain, A. K., Goel, S. C. and Hanson, R. D., **Hysteresis behavior of bracing members and seismic response of braced frames with different proportions,** *UMEE 78R3,* Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, July 1978, 365.

Bracing members are widely used in steel frames because of their ability to reduce displacements from lateral loading. Recent analytical studies of the hysteresis behavior of bracing members include the effect of end connections. There is a need to experimentally verify the findings of such analyses. Small square tube and angle specimens, with or without gusset plate connections, were subjected to large cyclic static and dynamic axial displacements. The results verified that the effect of end connections is to modify effective length and that hysteresis behavior can be represented by an equivalent pin-ended member having the same effective slenderness ratio. A new hysteresis model is proposed for steel tubular members that includes a reduction in compressive strength and an increase in member length with the number of cycles.

Braced frames are designed with different bracing patterns and member proportions that may significantly influence their behavior under severe dynamic forces. A study was performed (1) to define situations in which end moments dominate over axial forces in bracing members or vice versa, and (2) to develop an understanding of the inelastic behavior of braced frames.

Fifteen 7-story concentrically and eccentrically braced frames were analyzed under monotonic elastic and inelastic loading conditions. It was concluded that, in concentric braced frames, end moments and axial forces are equally important for bracing members of a slenderness ratio of 60, whereas buckling dominates for a slenderness ratio of more than 120. In eccentric frames, end moments dominate over axial forces for bracing members of a slenderness ratio of 60 or less; end moments and axial forces are equally important for a slenderness ratio of between 60 and 120; and buckling dominates for a slenderness ratio of more than 120.

Three split K-braced frames were designed in accordance with the 1976 Uniform Building Code with different girder, brace, and column proportions and were subjected to severe earthquake motion. The strong girder–weak brace combination produces excessive inelastic activity in the columns, whereas, with weaker girders, the inelastic activity is confined to the girders alone or distributed among the girders and bracing members.

6.6-41 Pekau, O. A. and Gocevski, V., **Behaviour of coupled non-linear shear walls,** *Canadian Journal of Civil Engineering,* 5, *3,* Sept. 1978, 367–373.

This paper describes an investigation of coupled nonlinear shear walls subjected to lateral load increasing monotonically up to overall collapse. Overall collapse includes base hinges in walls as well as the yielding of connecting elements over either all or some portion of the total height. Curves useful for the preliminary assessment of the potential seismic performance of a structural system are generated following a parametric scheme. Particular attention is focused on the connecting beam capacity and the system ductility capacity required to achieve overall collapse.

● **6.6-42** Gates, N. C., **The earthquake response of deteriorating systems,** *EERL 77-03,* California Inst. of Technology, Pasadena, Mar. 1977, 132.

This report is concerned with the earthquake response of deteriorating systems. A model for stiffness degrading or deteriorating systems is used to describe six different single degree-of-freedom systems. A numerical investigation of the response of these six systems is performed using an ensemble of twelve earthquakes. The response is studied at nine nominal periods of oscillation. The numerical results are presented as response spectra corresponding to six different ductilities. An approximate analytical method for

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calculating the earthquake response of deteriorating systems from a linear response spectrum is presented. The method, called the average stiffness and energy method, is based upon the premise that a linear system may be defined which is in some sense equivalent to the deteriorating system. The criterion for equivalence in this method is that the average stiffness of the deteriorating system be equal to the stiffness of the linear system and that the average energy dissipated by the linear system be the same as the average energy dissipated by the deteriorating system.

This new analytical method is compared to existing methods, and a comparison with the numerical results is also made. Based upon these comparisons, it is concluded that the average stiffness and energy method represents a significant improvement over currently available methods for predicting the earthquake response of deteriorating and nondeteriorating systems.

● **6.6-43** Tansirikongkol, V. and Pecknold, D. A., **Approximate modal analysis of bilinear MDF systems subjected to earthquake motions,** *UILU-ENG-78-2010, Structural Research Series No. 449,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, Aug. 1978, 219.

The study investigated two approximate methods for the modal analysis of hysteretic multidegree-of-freedom lumped mass structural models subjected to earthquakes. One method involved the use of elastic response spectra and the other involved inelastic response spectra. Both procedures were iterative and included a perturbation method to successively modify the original elastic mode shapes at each step to reflect yielding in the system. The procedures were developed and evaluated only for shear beam structural systems with bilinear hysteretic members. Extensive comparisons of exact and approximate responses were made for various 1-, 3-, and 10-degree-of-freedom systems. The records of four earthquakes were used, and several stiffness and strength parameters were varied. Maximum story displacements were generally predicted within about 5-40% accuracy. The equivalent nonlinear approach using inelastic response spectra appeared to give better accuracy than the equivalent linear approach using elastic response spectra.

● **6.6-44** Velkov, M., Gavrilovic, P. and Jurukovski, D., **Seismic stability of an 18-storey large panel building constructed in modified "Balency" precast system in Novi Beograd—analytical and experimental study,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-31, 1978, 245–253.

The Balency large-panel precast system, which is widely used throughout Europe, was originally designed for use in seismically inactive areas. Because the system is now being used in countries with a high degree of seismic risk, such as Yugoslavia, it has become necessary to modify it for use in the construction of earthquake-resistant structures.

This paper discusses experimental investigations of the system connections, and analyzes the behavior and response of a structure to a given seismic event. Suggestions are made regarding areas which need further research.

● **6.6-45** Shevlyakov, Yu. A., Tischenko, V. N. and Zelensky, G. A., **The seismoisolated building dynamics,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-23, 1978, 167–172.

The motion of a building supported by a kinematic vibration isolation system is examined. The isolated system consists of special elements which allow building mobility about the foundation. Assuming the base motion to be known, equations are obtained to describe the building motion and the isolated system elements as a system of rigid bodies. Relative motion of the building and building rotation are examined. Optimal parameters for dry friction dampers, which control building oscillation, are recommended.

● **6.6-46** Liauw, T. C., **Torsion of multi-storey spatial core walls,** *Proceedings, The Institution of Civil Engineers,* Part 2, **65**, Sept. 1978, 601–609.

Existing methods of analysis of multistory spatial core wall structures subject to torsion are reviewed; the method using the transfer matrix technique is then presented to deal with multistory spatial core walls of uniform cross section. A numerical example is given and compared with results obtained by other researchers. Since the mathematical operation in the analysis is confined to a matrix of maximum size 4x4, the method can be used in design offices with hand calculation or with a desk top minicomputer.

● **6.6-47** Sharma, S. K., **Dynamic response of reinforced concrete structures,** *Special Report M-243,* U.S. Army Construction Engineering Research Lab., Champaign, Illinois, July 1978, 27.

Beam-column and plane stress finite elements are described for an inelastic analysis of plane RC structures under seismic ground motion. Material nonlinearities in the beam-column finite element are taken into account by considering cyclic inelastic deformations throughout the element. The plane stress finite element allows for the cracking of the element in tension. These elements are incorporated in the DRAIN-2D computer program which was determined to be flexible and efficient. Preliminary results for simple structures showed that, with the addition

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of new finite elements described in this report, this program would be very useful for practical investigations of RC structures.

● **6.6-48** Chameau, J.-L. and Shah, H. C., **Dynamic testing of Gapec isolators,** John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Sept. 1978, 97.

This report describes the testing and dynamic analysis of a three-story building model equipped with Gapec isolators. The purpose of the work was to verify the accuracy of the previously observed behavior of the isolators (the effect on modal characteristics, damping, etc.) and to examine the response of structures equipped with the Gapec system when subjected to earthquake motions. Shaking table tests on a model give only its response to the particular table motion. Because time-scaling an accelerogram and applying it to a shaking table which has its own dynamic characteristics alter the frequency content of the motion, and because a model built in a laboratory is not truly representative of a real structure, the dynamic data presented in this report cannot be considered as truly indicative of values to be expected in an actual earthquake. However, the data does provide an indication of the overall dynamic behavior of a structure mounted with the Gapec isolators.

● **6.6-49** Emori, K. and Schnobrich, W. C., **Analysis of reinforced concrete frame-wall structures for strong motion earthquakes,** *UILU-ENG-78-2025, Structural Research Series No. 457,* Univ. of Illinois, Urbana, Dec. 1978, 209.

The nonlinear response and failure mechanism of reinforced concrete frame-wall systems are investigated with mechanical models for dynamic loads and static loads. Three mechanical models are presented: a concentrated spring model, a multiple spring model, and a layered model. These models take into account the inelastic behavior of a reinforced concrete cantilever beam. Ten-story reinforced concrete frame-wall structures are investigated. The stiffness characteristics of each constituent member are determined through one of the mechanical models by its inelastic properties or by a hysteresis model. Load increment analysis is used for a static loading case. The equations of motion are solved by a step-by-step integration procedure for a dynamic loading case. Computed results are compared with experimental results.

● **6.6-50** Suharwardy, M. I. H. and Pecknold, D. A., **Inelastic response of reinforced concrete columns subjected to two-dimensional earthquake motions,** *UILU-ENG-78-2022, Structural Research Series No. 455,* Dept. of Civil Engineering, Univ. of Illinois, Urbana, Oct. 1978, 210.

This study investigates the effects of two-dimensional earthquake motion on reinforced concrete (R/C) columns. An analytical model to represent the shear-deflection axial load relationship of R/C columns is developed from the stress-strain relationships of steel and concrete. An improved hysteresis model for steel included the Bauschinger effect, and the model for concrete included the deterioration of strength and stiffness under cyclic loading. The lumping of concrete at the end sections for calculating moment-curvature relationships in conjunction with an assumed curvature distribution along the column leads to an efficient procedure for the calculation of the shear-deflection axial load relationship for R/C columns. The analytical model compares favorably with the experimental results for both uniaxial and biaxial loading conditions. The analytical model predicts significant changes in the strength, energy absorption capacity, and accumulated damage responses of the column under biaxial deformations as compared to the corresponding responses under uniaxial deformations.

● **6.6-51** Amijima, S., Fujii, T. and Maenaka, M., **Dynamic response of adhesive bonded structures and joints** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 112, Nov. 1978, 889-896.

The dynamic responses of adhesively bonded structures under dynamic loading have been investigated by means of a finite element analysis technique. Stress wave phenomena need to be considered, in order to analyze the dynamic responses of structures or structural elements when they are subjected to abruptly changing dynamic loads. As a typical case of the dynamic responses of adhesively bonded structures, dynamic stress distributions of adhesively bonded joints were analyzed taking account of stress wave propagations in adherends and the effects of an adhesive layer. Two special problems have been studied. One is a two-dimensional analysis in which two-dimensional expansion of the adherends is considered. The other is a one-dimensional analysis but the effect of the viscoelastic characteristics of the adhesive layer is included in the analysis. The Voigt model assumption is applied to represent the viscoelastic properties of the adhesive layer. Finite element techniques, based on the method of weighted residuals using Galerkin's procedure, were applied to solve the partial differential equations which governed the dynamic behavior of the structures. Some typical cases of the dynamic responses of adhesively bonded joints subjected to impact loads at one end were calculated. It was found that the maximum adhesive shear stress occurs at both corners of a loaded side of an overlap. In all cases, a pulse rise-time affects the level of the adhesive shear stress. As the rise-time increases, the adhesive shear stress decreases rapidly. For the Voigt model assumption, a dashpot constant minimizes the adhesive shear stress.

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● **6.6-52** Fujiwara, T., **An approach to the aseismic design of the structural members,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 104, Nov. 1978, 825–832.

A method for the nonlinear earthquake response analysis of plane or space frame structures with local restoring force characteristics in the elastoplastic joints is discussed. By using this method, plane frame structures with or without braces subjected to random input or severe shocks and space frame structures subjected to multicomponent excitations are analyzed. Some of the results follow. The accumulation of the plastic axial deformation of column members leads to the collapse of the entire structure and the design of a structure with weak girders is recommended. The seismic-resistant elements reduce the ductility ratio responses of the main frame members. Two components of horizontal excitations decrease the safety of column members but the vertical component of the motion does not usually increase the local responses. One of the seismic-resistant design methods for structural members is presented by considering the above-mentioned local responses on the optimum distribution of the dynamic characteristics of structural elements.

● **6.6-53** Yahagi, K. *et al.,* **Earthquake observation and numerical analysis of a submerged tunnel** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 118, Nov. 1978, 937–944.

Based on earthquake observation and numerical analysis of part of the Tokyo Port Tunnel that is 1.0 km in length and has a rectangular section of 37.4 m x 8.8 m, the dynamic characteristics of the submerged tunnel during earthquakes were studied and a previously proposed numerical method for dynamic analysis was examined. From the records of the Izu-oshimo Kinkai earthquake (Jan. 1978; M = 7.0), the following results were obtained.

The strains resulting from the axial deformation of the tunnel (axial strains) are dominant and 2 ~ 3 times as large as the strains due to the bending deformation (bending strains) on the horizontal plane. The axial strains are large after 40 sec of the record and the very long periods of about 7.0 sec are dominant. The bending strains are large during 0 ~ 40 sec of the record and the comparatively short periods of about 1.0 sec can be seen. From the similarity of the power spectra, close correlations can be found between the axial strains and the velocities on the ground surface and between the bending strains and the accelerations.

Numerical analysis of the tunnel was carried out according to the following procedure. The tunnel was modeled as a beam on an elastic foundation of the ground. The deformations of the tunnel were calculated from statical equilibria where the displacement of the ground along the tunnel axis was forced to the tunnel with the spring of the ground. The displacement of the ground was obtained using the assumption that the displacement on the ground surface propagated along the tunnel axis. The wave velocities were determined from the cross-correlation functions of the acceleration records. The calculated axial strains show good agreement with the observed strains, but the bending calculated strains do not. One reason for the disagreement follows. The bending strains contain short periods that are very close to the predominant periods of the surface layer (estimated to be 0.9 sec ~ 1.0 sec). This suggests that it is not enough for the analysis to assume displacement only by the propagation of the seismic wave along the tunnel axis and that it is necessary to take account of the dynamic response of the surface layer.

● **6.6-54** Tamura, C., Okamoto, S. and Kato, K., **Earthquake observations on tunnels in the soft ground** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 120, Nov. 1978, 953–960.

Since 1970, the authors have conducted earthquake observations on actual tunnels constructed on soft ground in the Tokyo area. In this paper, observed data on the strains in the axial direction of the tunnels and on the deformation of the cross section of the tunnel that was constructed by shield method have been analyzed. For the strain of the tunnel wall in the axial direction of the tunnel during earthquakes, the relation between the maximum strains, the magnitude of earthquake, and the epicentral distances is shown. From results of observations, it is clarified that the maximum strains in the axial direction depend mainly on the magnitude of the earthquake and not upon epicentral distance. For the deformation of the cross section of the shield tunnel, the strains of the RC segments of the tunnel and variations of the gaps between the segments are observed, and it is noted that the deformation of the cross section of the tunnel mainly depends on the deformation of the surrounding ground of the tunnel, which is similar to the case of the strain in the axial direction. The dynamic behavior of the deformation of the tunnel is determined from vibration model tests of the tunnels. From the observations, it is shown that the maximum strains frequently are several times those strains of the axial direction of the tunnel.

● **6.6-55** Tanaka, T. and Kunii, T., **Non-linear restoring force characteristics of the pier having a well foundation estimated from earthquake records** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 70, Nov. 1978, 553–560.

Accelerographs atop the Ochiai Bridge pier and at the ground surface near the pier recorded a large amount of strong-motion acceleration data during the Matsushiro earthquakes. Data concerning maximum acceleration from 15 to 230 gal at the ground surface are used in this analysis. The bridge pier and the foundation buried in the ground are idealized as a one degree-of-freedom locking system. The values of linear damping constants and bilinear spring stiffness are evaluated. The calculated results show good agreement with the observed results. Several methods that indicate intensity of earthquake motion are used. These methods are maximum acceleration, total power, spectral intensity, power density distribution in time, and Fourier spectrum. From this analysis, the rate of decay of the natural frequency as the pier displacement response increases is shown.

● **6.6-56** Iemura, H. and Toyoda, I., **Structural deterioration and earthquake failure criteria** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 172, Nov. 1978, 1369-1376.

A simplified model for the deterioration of reinforced concrete structures during strong earthquakes is proposed. In the model, the equivalent stiffness and energy-absorbing capacity of structures are assumed to degrade with increasing damage, an idea derived from the theory of low-cycle fatigue. The study outlines the applicability of the proposed method by examining results of dynamic bending tests on reinforced concrete specimens. A new deteriorating hysteretic model derived from the results of experiments is proposed to calculate seismic response. Three response values are compared to determine which parameter gives the best measure of the earthquake failure criteria of deteriorating hysteretic structures.

● **6.6-57** Yoshimura, K. and Kikuchi, K., **Static and dynamic analyses of a reinforced concrete hotel building damaged during the Oita earthquake of April 21, 1975**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 185, Nov. 1978, 1473-1480.

Linear static and dynamic analyses are presented of a reinforced concrete hotel building damaged beyond repair during the Oita earthquake of Apr. 21, 1975. The damaged building is idealized as a three-dimensional mechanical model. The dynamic response of this idealized structure, the lateral motions of which are coupled with the torsional motion, is studied; and the effects of the torsional motion on the elastic response are investigated. In the static analysis, two lateral force distribution shapes, which are specified in the current Japanese building standard and in the U.S. Uniform Building Code, are used. Results of the static analysis are compared with those of the dynamic response analysis.

● **6.6-58** Yamada, M. and Kawamura, H., **Ultimate aseismic capacity of structures-based on earthquake ground motions and elementary resonance fatigue characteristics of structures** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 171, Nov. 1978, 1361-1368.

A method for evaluating the ultimate seismic-resistant capacity of structures is proposed. The method uses idealized earthquake ground motions and elementary resonance fatigue characteristics of structures based on the resonance response principle.

● **6.6-59** Hiramatsu, A., **Earthquake responses of multilayer structures considering the non-linear hysteresis of the bottom layer** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 149, Nov. 1978, 1185-1192.

Earthquake response behavior of multistory buildings is discussed with attention paid to nonlinear restoring force characteristics of the base story. If the stiffness and the bearing strength capacity of the base story are less than those of an upper story, the response displacement of the base story will be in the inelastic range. Under such circumstances, it can be assumed that the upper story remains in the linear elastic region, while the base story has nonlinear hysteretic relationships. Using this assumption, a multistory building can be idealized by a two-mass system model instead of a multi-mass system model. The response waves of the two-mass system are similar to those of the multi-mass system. These facts suggest that the general response behavior of two-mass systems should be considered when studying the behavior of multistory buildings. The earthquake response of two-mass systems is examined.

A review of theoretical nonlinear responses shows that the center of the displacement wave has a tendency to shift from its original axis; i.e., a building vibrates in an inclined state. This tendency depends upon the restoring force characteristics of the ground accelerograms. Since the shift of the wave center is closely related to the displacement value of the adjacent peak or trough, it is convenient to study how the peak or trough point is formed in order to study the wave center shift. It is indicated that, even in the case of a multi-mass nonlinear system, the equivalence of hysteretic energy exists just as for a one-mass system. How much effect the restoring force characteristics have on peak or trough position will be estimated using the concept of equivalence of hysteretic energy. The results indicate that it is important to evaluate carefully the area of hysteresis loops during cyclically repeated loading at the so-called slip region.

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● **6.6-60** Minami, K. and Nishimura, Y., **Hysteretic characteristics of beam-to-column connections in steel reinforced concrete frames** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 167, Nov. 1978, 1329–1336.

The failure mechanism, load-carrying capacity, and hysteretic characteristics of the beam-to-column connection in a steel-reinforced concrete frame subjected to monotonous and alternately repeated loading are examined. The experimental variables are the type of connection and the ratio of beam width to column width. Twenty-five specimens were tested. The specimens were designed to prevent flexural and shear failure of the beams and columns, whose connection panels were made of pure steel or steel and concrete.

On the basis of the test results, a mathematical model of the composite connection failure in shear is proposed. The model is composed of four fundamental elements: a web panel of encased steel, a rigid frame composed of four flange elements surrounding the web, a concrete panel zone surrounded by steel flanges, and a reinforced concrete panel element with a width equal to the sum of the distance from the tip edge of the steel flange to the side surface of the adjacent beam on both sides. Some examples of calculated hysteresis loops for the connection which failed in shear are shown.

From the test results, the following conclusions are obtained. (1) The failure mode of the beam-to-column connection is strongly affected by the type of connection. (2) The shear strength of the interior connection is considerably larger than that of the exterior and corner connections, and the shear strength of each type of connection increases with an increase in the ratio of beam width to column width. The ultimate shear stress of the concrete panel is well estimated by the proposed equation. (3) The calculated inelastic response of the composite corner and exterior connection is in good agreement with the measured response. The maximum load-carrying capacity and stiffness recovery resulting from closing of the cracks are well predicted by the theory, except for the sudden change in the stiffness in the loops.

● **6.6-61** Tankanashi, K., Udagawa, K. and Tanaka, H., **Earthquake response analysis of steel frames by computer-actuator on-line system**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 166, Nov. 1978, 1321–1328.

Improvements in the nonlinear analysis of structural response to seismic motion are described and example analyses are given. The nonlinear response of a 1-bay, 2-story steel frame with two degrees-of-freedom is demonstrated. A frame with bolted joints also is analyzed. This frame has very complicated restoring force characteristics because of slippage at the joints.

● **6.6-62** Ogawa, J., **The study on the restoring force characteristics of the reinforced concrete**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 164, Nov. 1978, 1305–1312.

The experimental investigation of the hysteretic behavior of a reinforced concrete test specimen subjected to tensile and compressive axial loading reversals is discussed in relation to the strength and the stiffness reduction in the post-elastic region and the bond effects. The specimen is discretized into small elements and three nonlinear springs involving the bond are idealized. Analytical and experimental results are compared and good agreement is found.

● **6.6-63** Nagasaka, T., **Restoring force characteristics of R/C framed structure models by static analysis**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 163, Nov. 1978, 1297–1304.

The author has previously described an analytical method to clarify the restoring force characteristics of R/C framed structures subjected to repeated horizontal reversals. The method is based on the material properties of the concrete and reinforcing bars and the geometrical properties of the structure. Using this method, this paper examines the restoring force characteristics of an entire structure by analyzing two full-size model frames of three stories and five spans. It is shown that the restoring force characteristics are influenced by such factors as the interactive bonds between the concrete and steel bars and the probable axial forces in the beams.

● **6.6-64** Tani, S. and Soda, S., **Dynamic analysis of reinforced concrete frame subjected to earthquake excitation in both the horizontal and the vertical directions** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 139, Nov. 1978, 1105–1112.

Earthquake excitation is essentially a three-dimensional motion and its vertical motion induces considerable axial force in a column which may affect the restoring force characteristics of a reinforced concrete frame. This paper examines the intense-earthquake vertical-load effect on the dynamic behavior of a reinforced concrete frame. An experiment is described for modeling the restoring force characteristic curve of a reinforced concrete frame subjected to alternating static load in the horizontal and vertical directions. When the vertical load changes, the skeleton curve and the hysteretic loop gradually approach, with change in horizontal load, the curve and loop obtained from an experiment using a constant vertical load. An earthquake response analysis shows that the vertical motion of the earthquake has little effect on the displacement and velocity response. However, the increase or decrease in the acceleration and shear force response is 10% of those values calculated without consideration of an alternating vertical load effect.

● **6.6-65** Yamazaki, Y., **Inelastic response of two-dimensional structures with eccentricity during strong motions,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 135, Nov. 1978, 1073–1080.

It is important in the earthquake-resistant design of structures to take into account the effect of eccentricity on the distribution of rigidity of a structure. The inelastic response of two-dimensional structures subjected to strong motions is investigated in this paper. A model, idealized by a shearing system composed of frames in two directions, and a stiffness-degrading model are used to examine the restoring-force displacement relationship of each frame.

● **6.6-66** Sato, T. and Hannuki, T., **Bounds on the plastic curvature of steel frames and combined bi-linear type nonlinear analysis considering shear deformations** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 140, Nov. 1978, 1113–1120.

This paper describes a correction term taking into consideration the bounds on shear strains and the approximate bounds on the plastic curvature of multistory frames. A method is introduced for bilinear geometrical and material nonlinear analysis. The method is used to analyze beam-to-column connections of H-shaped steel members and shear deformations of members in steel frames. The results of this analysis are compared with those of the horizontal alternate loading tests of two-story steel frames. It was found that the premature brittle fracture caused by artificial defects at welding spots reduced the degree of redundancy and the ultimate load of the multistory frame but that the plasticity of the system was preserved. The proposed analytical model was found to be computationally efficient.

● **6.6-67** Toki, K. and Kubota, M., **Nonlinear response of continuous bridge to travelling seismic wave** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 134, Nov. 1978, 1065–1072.

The paper deals with the effects of a traveling wave on the response of a five-span continuous bridge. The ground motion at discrete points along the bridge is determined from a dispersion curve which is detected from actual strong-motion accelerograms recorded simultaneously at two sites. The displacement curve for the longitudinal and vertical components implies a Rayleigh-wave-type ground motion because of the phase difference between the two components.

The bridge model is illustrated schematically. An abutment and three piers are connected to the girder by sliding supports having a restoring property; two other piers are attached to the girder. The abutment and two piers are welded to the base rock, and three piers are supported on diluvial deposits of different thicknesses. In one case, the ground motions are applied at the rock surface of corresponding points to the abutment and piers; in all other cases, the effects of the diluvium are not considered. The damping coefficients are deduced from a damping factor corresponding to the modal damping natural period. The girder and piers are represented by beam elements and each element is connected to the other by springs which transmit the normal, shear, and frictional forces and moments. The equation of motion for the girder and piers is given for longitudinal and vertical motion and for rotation. The equation of motion for the foundations also is given. The rocking angle at the bottom of the foundations is determined from the velocity time trace of the vertical components. The effects of phase velocity on the response acceleration and section forces are illustrated. The traveling wave effects are most pronounced for the response acceleration and bending moments of the piers, for the normal force at the pile center spans, and for the rocking motion of the foundations, even for a long wave length. Decreases in horizontal acceleration, bending moment, and shear force of the girder are caused by the traveling wave. The existence of diluvium causes a noticeable difference in the bending moment of the girder and piers.

● **6.6-68** Kaneko, Y. and Tanaka, Y., **Shear failure mechanisms of reinforced concrete short columns,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 162, Nov. 1978, 1269–1296.

One of the most important problems in the seismic-resistant design of reinforced concrete structures is preventing brittle column failure caused by shear loading. In this paper, brittle failure of short columns resulting from shear slip in diagonal cracks is analyzed. It is assumed that column deformation caused by shear loading is one of three kinds, i.e., flexural, bond failure, and shear slip deformation. It is also assumed that the ultimate state is reached when the shear load causes shear slip along diagonal cracks in core concrete, producing yield confining forces in the tie reinforcing bars. Equations for the ultimate shear strength of short reinforced concrete columns are derived, and the analytical results show good agreement with the results of

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experiments conducted by the authors and other researchers.

● **6.6-69** Muto, K. *et al.*, **Nonlinear earthquake response analysis of highrise building** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 160, Nov. 1978, 1273–1280.

This paper presents a simplified method for the dynamic analysis of the behavior of a three-dimensional structure in the elastic-plastic range. Each plane frame is converted to a bending and shearing model, and, to account for the three-dimensional effects of the structure, the bending deformation in the direction of excitation is connected with that in the orthogonal direction. Bilinear or trilinear idealized hysteresis loops are included for the shear deformation of the bending and shearing models in the direction of excitation. An example computation is given for a 38-story building with a notched, V-shaped framing plan.

● **6.6-70** Watt, B. J. *et al.*, **Earthquake survivability of concrete platforms,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. II, OTC 3159, 1978, 957–973.

A series of nonlinear dynamic analyses was conducted to assess the survivability of a typical concrete gravity platform during extreme magnitude earthquakes. The characteristics of the structure, its foundation, and the earthquake inputs were varied among 15 analysis cases. Scaled natural and artificial accelerograms with free field velocities up to 40 in. per sec were used. It was concluded that suitably designed platforms are capable of surviving extreme ground shaking conditions likely to be associated with rare intense earthquakes in the Gulf of Alaska.

● **6.6-71** Nachbar, W. and Furgerson, R., **Stability under seismic loading of buildings with fully cracked wall-floor joints,** *North American Masonry Conference Proceedings,* Paper No. 55, 14. (For a full bibliographic citation, see Abstract 1.2-12.)

Structural collapse caused by loss of kinematic integrity is studied. In particular, the failure of a floor slab and a shear-wall model structure caused by loss of support is considered. It is assumed that all connection reinforcement of the floor slabs and shear walls has failed, and that motions of the floor slab relative to the shear walls caused by acceleration applied to the foundation are restrained by friction only. Constant-coefficient Coulomb friction is used in the analysis. Previous work of the authors has shown that this method provides a good approximation to the experimentally observed behavior of cracked joints in concrete masonry blocks, provided that the blocks slide against each other a short distance in comparison with the shear-wall widths seen in standard construction practice. The collapse time is defined as the instant when the floor slab first ceases to be in contact with its supporting walls. Since vertical displacements are not considered in the present model, this definition of collapse implies loss of structural integrity. The seismic foundation acceleration input is simulated by a sinusoidal oscillation contained within an envelope that has a shape representative of an earthquake. A number of envelope shapes are considered. The results of computations show that the relationship between collapse time, maximum foundation acceleration, earthquake duration, and predominant frequency is surprisingly well defined.

● **6.6-72** Arya, S. K. and Hegemier, G. A., **On nonlinear response predictions of concrete masonry assemblies,** *North American Masonry Conference Proceedings,* Paper No. 19, 24. (For a full bibliographic citation, see Abstract 1.2-12.)

Recent experimental investigations on concrete masonry indicate that the response of a masonry assemblage is nonlinear under both monotonic and cyclic loading conditions. This paper is concerned with the analytical prediction of such nonlinear response using the fundamental properties of the basic constituents of concrete masonry, which are derived from small-scale experiments on each constituent. The finite element method is the basic analytical tool in this study. A finite element micromodel of reinforced concrete masonry is developed. The model has two main features: (1) a method for representing pre- and post-fracture behavior of joints or interfaces in a masonry assemblage and (2) a nonlinear material model which accounts for masonry cracking and the effects of reinforcing steel. The material model is based upon maximum tensile stress theory for cracking as a result of tension and the von Mises yield surface in conjunction with a strain softening, unconstrained flow rule for failure in compression. Reinforcing steel is assumed to be elastic-perfectly-plastic in both tension and compression.

The model is implemented into an out-of-core version of the computer code NONSAP. The effectiveness of the model is demonstrated by comparison of the predicted and experimental behavior of concrete masonry shear walls subjected to both monotonic and cyclic deformation histories. Excellent correlation between the experimental results and the analytical predictions is observed.

● **6.6-73** Adham, S. A. and Ewing, R. D., **Interaction between unreinforced masonry structures and their roof diaphragms during earthquakes,** *North American Masonry Conference Proceedings,* Paper No. 57, 16. (For a full bibliographic citation, see Abstract 1.2-12.)

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Numerous wood roof diaphragms are found in masonry buildings in highly seismic zones. The effect on the response of masonry structures of varying diaphragm stiffness was studied. A lumped-mass analytical model representing the interaction of a masonry wall and a diaphragm was developed. This model was then subjected to an earthquake acceleration time history input that corresponded to the intensity level of the Los Angeles area. Plywood, diagonal, and straight-sheathed diaphragms were examined. Results indicate that the response of a wood diaphragm is highly nonlinear, and that low-amplitude tests are not adequate for predicting the response of these diaphragms in highly seismic zones. It was concluded that soft wood diaphragms attenuate input earthquake accelerations and result in the transmission of lower shear forces to the masonry walls than those forces obtained from stiff diaphragms; however, the soft diaphragms exhibit larger corresponding midspan deflections than do the stiff diaphragms.

● **6.6-74** Igarashi, S. and Ogawa, K., **Studies on kinematic model of steel frames for aseismic design (Part 2: tentative proposal of equivalent continuous system)** (in Japanese), *Transactions of the Architectural Institute of Japan, 272,* Oct. 1978, 53–62.

This study devises a simple kinematic model representing the overall behavior of a framed structure under earthquake excitations. In a previous paper the authors showed that inelastic responses of a framed structure were strongly affected by the yield interaction of story forces. The present study develops a yield interaction equation that is a function of a story shear force, a story axial force, an overturning moment, and transverse forces on beams caused by gravity and dynamic effects. From this equation, an equivalent continuous system is devised; the system is a mathematical model for an inelastic framed structure incorporating the effects of yield interactions between story forces and work-hardening of the material. Also taken into account is the P-Δ effect on an entire story. Numerical examples are given. The results show that the proposed method, as compared with a more accurate but complicated analysis, gives reasonable approximations for such overall structural responses as the shear force and the horizontal displacement of each story. The method may be applicable to seismic response analysis of multistory framed structures.

● **6.6-75** Hong, G., and Tanaka, H., **Hysteretic energy dissipation of single-degree-of-freedom system subjected to white noise excitation** (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 99–103.

A new analytical technique is presented for the estimation of the probability distribution of hysteretic energy dissipation for the stationary response of a bilinear hysteretic single degree-of-freedom system subjected to white noise excitation. The results are compared with results determined by Monte-Carlo simulation.

● **6.6-76** Muto, K. *et al.*, **Structural test and analysis on the seismic behavior of the reinforced concrete reactor building (Part 2: earthquake response)** (in Japanese), *Transactions of the Architectural Institute of Japan, 271,* Sept. 1978, 37–44.

The dynamic behavior of a reactor building when subjected to severe earthquakes is analyzed and discussed. The model reactor building used for dynamic analysis was composed of the same structural features as the tested specimen, except that it was 25 times larger and had additional steel framing on the top floor portion. Weights located on every floor were chosen to correspond to actual loads. A vibration model is idealized to have lumped masses interconnected by flexural and shearing elements. The strength deformation characteristics of the elements were formulated in Part 1 of the paper. The nonlinear dynamic responses of the model to the input ground motions are calculated by the direct step integration method.

The responses to strong earthquakes with maximum accelerations up to 600 gals are summarized as follows: (1) Because of the strong ground motion, the model structure always entered into the nonlinear ranges. For instance, flexural and shear yielding specified by the test results occurred during earthquakes with maximum accelerations of 400 gals or more. (2) Structural damages estimated by the test results were, however, very minor, even during the largest earthquake, with 600 gals acceleration. In comparing the ultimate strength and the largest deformability with the response values, it is concluded that the safety factors of the model structure are satisfactory.

● **6.6-77** Udagawa, K., Takanashi, K. and Tanaka, H., **Non-linear earthquake response analysis of structures by a computer-actuator on-line system (Part II: response analyses of one bay-one story steel frames with inelastic beams)** (in Japanese), *Transactions of the Architectural Institute of Japan, 268,* June 1978, 49–59.

The authors have developed a method for the nonlinear earthquake response analysis of structures by a computer-actuator on-line system based on the real behavior of structures or structural members. Details of the system and one of the numerical integration methods for an equation of motion were described in an earlier paper. In this paper a fundamental flow chart of the system is shown. Since the restoring forces of a nonlinear structure are a function of time and deformation, the real responses are calculated by using the instantaneous restoring forces. Therefore, the instantaneous restoring forces are obtained by structural experiments controlled by a computer which simultaneously calculates the response.

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The critical elements in this analysis are the numerical integration method for an equation of motion and accurate measurements of restoring forces and deformations. Two kinds of numerical integration are used: (1) to solve the equation of motion by the linear acceleration method, using the secant stiffness at a step of the specimen in the structural experiment. In this method, a convergent response calculation must be made to determine an accurate stiffness; and (2) to solve the equation of motion by an open-type finite difference method, using the instantaneous restoring force of the specimen in the structural experiment. Method (2) is adequate for the on-line test, because the accuracy of an actuator and measurements of the restoring force have less effect on the accuracy of the solution of the equation of motion and are adaptable to a response analysis of multistory structures. However, if the restoring forces of an analyzed structure cannot be obtained directly from the experiment or if the stiffness of a specimen must be used in the analysis, method (1) must be adopted.

This paper examines the responses of one-bay, one-story steel frames with inelastic beams. These responses are compared with the responses obtained by the mathematical expression of the restoring force characteristics of beams, where the strength deterioration of the beams is not considered. The calculated restoring force characteristics are compared with those obtained by the on-line test.

● **6.6-78** 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 1: shearing deformation of the beams and columns of the frames)**, *Transactions of the Architectural Institute of Japan, 273,* Nov. 1978, 25-31.

To analyze shear walls more precisely than has been done in the past, shearing deformation of the beam and the frame columns is induced. The numerical results for a shear wall subjected to shearing forces caused by earthquakes are compared with the results of previous studies that neglected shearing deformation.

● **6.6-79** Mochizuki, T. *et al.*, **On the conversion of a hysteretic structure into the restoring force model (part 5)—comparison the earthquake response analysis by power functional hysteretic system with dynamic test** (in Japanese), *Transactions of the Architectural Institute of Japan, 265,* Mar. 1978, 63-70.

● **6.6-80** Inoue, K. and Ogawa, K., **A study on the plastic design of braced multi-story steel frames (Part 2: on the overall static and dynamic behaviors of plastically designed multi-story braced frames)** (in Japanese), *Transactions of the Architectural Institute of Japan, 268,* June 1978, 87-98.

In order to determine the inelastic behavior of braced frames in which sway deflection resulting from column shortening and elongation is more than negligible, an overall analysis is essential. This paper includes a method of static and dynamic analysis in which the incremental member stiffness is determined by the generalized hardening hinge method. Overall inelastic static and dynamic behaviors of multistory steel braced frames are examined by the method. The braced frames analyzed are 10-story, 3-bay frames designed by a plastic design method proposed in Part 1 of this paper. Response quantities of the braced frames are compared with those of a plastically designed open frame. Numerical results show that most of the input energy is dissipated by the bracing members. Therefore, the inelastic dynamic responses of braced frames are quite small and are uniform along the height of the frame in comparison with the responses of the open frame.

● **6.6-81** Igarashi, S. and Ogawa, K., **A study on the kinematic model of steel frames for aseismic design (Part 1: effect of vertical ground motion on the seismic response)** (in Japanese), *Transactions of the Architectural Institute of Japan, 268,* June 1978, 77-85.

As the basic research in the development of a kinematic model, this paper clarifies the effect of vertical ground motion on seismic response. The inelastic response of steel frames subjected to the horizontal and vertical components of an an earthquake is compared to the response when the frames are subjected to only the horizontal components of the earthquake. The inclusion of vertical ground motion can result in a significant increase in the ductility requirements of the upper-story members, whose design is controlled by the vertical loading. The inelastic deformation of the lower-story columns in the highrise building may be affected by vertical ground motion in terms of increasing axial forces. It is concluded that the effects of vertical ground motion on seismic response are large enough to warrant consideration in earthquake-resistant design practice. It should be noted that the inelastic interaction between horizontal inertia forces caused by horizontal ground motion and vertical inertia forces caused by vertical ground motion may play an important role in explaining the effects of vertical ground motion on seismic response.

● **6.6-82** Igarashi, S., Inoue, K. and Ogawa, K., **A study on the plastic design of braced multi-story steel frames (Part 1: the vertical distribution of the ratios of story shear force shared by bracings to total story shear force)** (in Japanese), *Transactions of the Architectural Institute of Japan, 263,* Jan. 1978, 43-50.

This paper gives a method for obtaining the vertical distribution of the ratios (β) of the story shear force shared by bracings to the total story shear force along the height of the frame when the ultimate factored design loads are

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given. The effect of horizontal deflection caused by column shortening and elongation of the braced bay on the ratio β is taken into account. An example is illustrated for ten-story, three-bay, braced frames. Tensile and compressive bracing members are designed by formulas based upon the cyclic reduction in energy-absorption capacity. It is shown that the vertical distribution of β is significantly affected by column shortening and elongation of the braced bay and by the load factor at the time of brace yielding.

● 6.6-83 Nath, Y. and Alwar, R. S., **Non-linear static and dynamic response of spherical shells,** *International Journal of Non-Linear Mechanics,* 13, *3,* 1978, 157–170.

In this paper, an analytical technique using Chebyshev series expansion is used to study the nonlinear transient behavior of shallow spherical shells with and without damping. The two coupled nonlinear differential equations governing the shallow shell behavior are initially linearized using Taylor's series expansion. Results are presented for three types of transient loadings, namely, step function, *N*-shaped pulse, and sine wave pulse. It is shown that accurate results can be obtained using a five-term Chebyshev series expansion, which is unlikely by conventional methods.

● 6.6-84 Crespo da Silva, M. R. M., **Harmonic non-linear response of Beck's column to a lateral excitation,** *International Journal of Solids and Structures,* 14, *12,* 1978, 987–997.

The nonlinear response of a column with a follower force (Beck's column) subjected to a distributed periodic lateral excitation, or to a support excitation, is determined. An analytical solution for the response amplitude in terms of the loading and system parameters is obtained by a *perturbation analysis* of the differential equations of motion. Nonlinear inertia and nonlinear curvature terms are taken into account in the formulation of the differential equations.

● 6.6-85 Lipson, S. L. and Haque, M. I., **Elasto-plastic analysis of single-angle bolted-welded connections using the finite element method,** *Computers & Structures,* 9, *6,* Dec. 1978, 533–545.

The results of an extensive numerical elastoplastic study of single-angle connections subjected to cyclic loading consisting of end shear and bolt moment are discussed. The thrust of the study is directed toward an improved understanding of the stress variations and the propagation of plastic zones in the vicinity of the weld.

● 6.6-86 Mitani, I., **An elastic-plastic analysis of a restrained steel bar under repeated eccentrical axial loading** (in Japanese), *Transactions of the Architectural Institute of Japan, 274,* Dec. 1978, 65–73.

A bar elastically restrained against rotation at both ends is analyzed based on the differential equation for the elastic bending of an axially loaded member and commonly adopted yield conditions. The analytical results are compared with experimental results. The cyclic behavior of a restrained bar is compared with the behavior of a pin-supported bar at both ends having the same slenderness ratio as the restrained bar. The effects of the eccentric axial load on the behavior of a bar are also investigated. The analytical results are as follows. (1) The analytical cyclic behavior predicts fairly well the experimental behavior, expect for the maximum compression load at each loading cycle and the initial maximum tensile load of a pin-supported bar subjected to an eccentric load. (2) In the elastic-plastic region of the axial load displacement curves, the change in stiffness of a restrained bar is less than for a pin-supported bar having the same slenderness ratio as the restrained bar. Deterioration after the maximum compression load of a restrained bar at each loading cycle was less than for a pin-supported bar. (3) Close agreement between analytical and experimental values of magnification α for load-carrying capacity at the reversed points was obtained by using identical restraining spring stiffnesses. (4) The effect of the eccentricity of the axial load on the cyclic behavior of a restrained bar is very large in the elastic-plastic region of the axial load-displacement curves.

● 6.6-87 Sinha, S. C. and Chou, C. C., **On non-linear oscillations with slowly varying system parameters,** *Journal of Sound and Vibration,* 61, *2,* Nov. 22, 1978, 293–301.

This paper considers an approximate analysis of nonlinear oscillation problems with slowly varying system parameters. From the differential equations for amplitude and phase, set up by the method of variation of parameters, the approximate solutions are obtained by using the generalized averaging method of Sinha and Srinivasan based on ultraspherical polynomial expansions. The Bogoliubov-Mitropolsky results are given by a particular set of these polynomials. Problems of a single degree-of-freedom system as well as monofrequency oscillations in systems with multiple degrees-of-freedom are considered. The approach is illustrated by an example, and the results are compared with the numerical solutions. A close agreement is found.

● 6.6-88 Kelly, J. M. and Tsztoo, D. F., **The development of energy-absorbing devices for aseismic base isolation systems,** *UCB/EERC-78/01,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Jan. 1978, 53. (NTIS Accession No. PB 284 978)

This report describes the behavior of mild steel energy-absorbing devices that can be used in earthquake isolation systems. The devices are rigid under service-type loading, but yield and absorb energy under large earthquake-type loading. The devices are shown to have a

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substantial hysteretic energy-absorbing capacity over a useful life in excess of 300 cycles, far exceeding any load duration which can be expected from earthquake loadings. The hysteresis loops developed by sinusoidal loading of the devices effectively bounded the loops obtained by the random loading of the devices. The actual incorporation of the devices in a structural steel frame is being investigated in ongoing research.

● **6.6-89** Imbsen, R. A., Nutt, R. V. and Penzien, J., **Seismic response of bridges-case studies,** *UCB/EERC-78/14,* Earthquake Engineering Research Center, Univ. of California, Berkeley, June 1978, 201. (NTIS Accession No. PB 286 503)

Presented are the results of six case studies conducted on each of three bridges (the Route 80 Onramp Undercrossing, the Northwest Connector Overcrossing, and the Southwest Connector Overcrossing, designed by the California Dept. of Transportation) when subjected to strong seismic excitation. The dynamic responses of each bridge for separate excitations in the longitudinal and transverse directions are determined using the response spectral, linear time-history, and nonlinear time-history approaches. Maximum response values are interpreted in terms of current design procedures and code provisions.

● **6.6-90** Zagajeski, S. W., Bertero, V. V. and Bouwkamp, J. G., **Hysteretic behavior of reinforced concrete columns subjected to high axial and cyclic shear forces,** *UCB/EERC-78/05,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1978, 289. (NTIS Accession No. PB 283 858)

An investigation of the inelastic behavior of short reinforced concrete columns is presented. The results of both experimental and analytical studies are reported. The experimental program was planned to evaluate the hysteretic behavior of short reinforced concrete columns subjected to high axial loads and cyclic shear forces. Column transverse reinforcement was designed with the objective of providing a shear strength, as defined by the UBC 1973 requirements for ductile moment-resisting frames, which would be sufficient to develop the column moment capacity under selected design axial loads. The columns were tested as components of a one-bay, two-story subassemblage of a typical spandrel wall frame. The magnitude of the axial load, the type of transverse reinforcement, and the deformation history were varied to evaluate their influence on column behavior.

All model columns tested experience significant inelastic deformation, and all but one develop the shear force corresponding to their respective analytical moment capacity before either a sudden diagonal tension failure or a significant degradation in column shear strength. Shear degradation is caused by either bond deterioration or a degradation in the longitudinal shear transfer mechanism. Cyclic stiffness degradation is associated with cyclic inelastic behavior. The results demonstrate that spiral transverse reinforcement is more effective in maintaining the shear strength of a member than rectangular ties. Bond deterioration, however, can still lead to significant shear degradation and create anchorage problems for the longitudinal reinforcement in spiral columns.

In the analytical phase of the investigation, a model was formulated to facilitate the analytical study of crack behavior, i.e., crack formation and propagation and the force transfer across cracks, in reinforced concrete members. The analytical model is based on the finite element method of structural analysis. Concrete is modeled as plane stress finite elements and steel reinforcement is modeled as bar elements. The nonlinear material behavior of both steel and concrete is approximated. Concrete cracking is included in the model by a crack line approach. The bond between steel and concrete is included by using different nodes to define the steel and concrete elements and coupling these nodes with dimensionless bond-link elements. The shear forces developed across cracks by aggregate interlock and dowel action of the reinforcement are also modeled by using dimensionless links.

The solution strategy developed enables the changes in structure topology, which are required to effect cracking in the model, to be made within the context of an incremental solution process. In its current stage of development, the cracking model has limited application. Suggestions to remedy shortcomings which limit application are made.

● **6.6-91** Mohan, L., **Reduction of input seismic forces to base isolated structure,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 255-276.

An 11-story stiff reinforced concrete structure, an 11-story reinforced concrete structure with a flexible basement but with no damper, and an 11-story reinforced concrete structure with a flexible basement and a steel damper of varying properties have been analyzed. The maximum responses of the structures to different earthquakes (e.g., El Centro 1940 NS, Taft 1952 EW and TOKYO 101 with maximum ground accelerations of 250 and 400 gals each) are considerably reduced. The reduction, however, varies with each earthquake, maximum ground acceleration and type of damper.

● **6.6-92** Chavez Zegarra, J. W., **Comparison of response analysis of R.C. frames represented by shear model, S-B model and frame model,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 335-356.

This paper studies the response analysis of R.C. frames represented by a shear model and by a flexural shear model (S-B model) and compares the results with a rigorous model using dynamic frame response analysis. The parameters for the shear model and the S-B model were obtained by utilizing a static frame analysis. The structures analyzed were R.C. frames of 4, 8 and 12 stories (2 cases each) in which the dimensions of the beams were different in each case and in which the strength was nearly the same. The buildings were designed in accordance with the Peruvian code. All the structures were subjected to the El Centro and Taft motions with a maximum acceleration of 400 gals. The results show a failure of the beam hinge mechanism and that the result for the S-B model compares more favorably with the frame model result than does the result for the shear model.

● 6.6-93 Saune Rojas, A. A., **Dynamic behavior of multistoried reinforced concrete buildings,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 315-333.

The dynamic behavior is studied of 4-, 8-, and 12-storied buildings with open frames and with shear wall frames. A digital computer is used to determine the linear dynamic response of the buildings. The computer programs (FRAME-1, FRAME-2, and FRAME-3) are used. The response characteristics studied include maximum lateral displacement, maximum relative displacement, shear force, and seismic force.

● 6.6-94 Meek, J. W., **Dynamic response of tipping core buildings,** *Earthquake Engineering & Structural Dynamics,* **6,** 5, Oct.-Sept. 1978, 437-454.

When subjected to major earthquakes, core-stiffened buildings may begin to tip, i.e., the overturning moment on the footing of the core becomes so large that the footing breaks contact with the ground and begins to rock. A method is described for including the effects of tipping in the analysis of multistory core-braced structures. Curves are presented which summarize the maximum response to both pulse and earthquake excitations; these data are elucidated via a typical design example. By comparison to fixed-base behavior, tipping greatly reduces the base shear and moment. This makes possible a more economical design. However, attention must be devoted to avoiding potential soil-mechanics problems associated with the wobbling behavior of the tipping core.

● 6.6-95 Mochizuki, T. and Kitagawa, H., **Equivalent restoring force model of a yielding structure,** *Memoirs of Faculty of Technology, Tokyo Metropolitan University,* **27,** 1977, 2589-2606.

● 6.6-96 Kunii, T. and Fukui, T., **Non-linear response characteristics of simple system subjected to earthquakes in close area,** *Memoirs of Faculty of Technology, Tokyo Metropolitan University,* **27,** 1977, 2571-2577.

The nonlinear seismic response of a single degree-of-freedom structure is treated. Bilinear restoring force characteristics are induced. The response characteristics are discussed in the form of displacement and acceleration response spectra. One group of earthquakes analyzed has a distant focus and a relatively large magnitude. Another group has a focus in a nearby area and a relatively small magnitude. The difference of the response for these two types of input is clarified and the response characteristics to earthquakes in the nearby area are studied. It is concluded that the displacement response spectra in the nearby area are always smaller than those spectra for distant earthquakes, except in the lower and higher frequency ranges.

● 6.6-97 Nakata, S., Sproul, T. and Penzien, J., **Mathematical modelling of hysteresis loops for reinforced concrete columns,** *UCB/EERC-78/11,* Earthquake Engineering Research Center, Univ. of California, Berkeley, June 1978, 95.

This paper estimates lateral force-deflection curves for reinforced concrete columns subjected to cyclic transverse loads and constant axial loads. These curves are determined in relation to particular column parameters such as shear-span ratio, longitudinal and horizontal reinforcement, and axial force. The data for this project were obtained from a series of tests reported by Atalay and Penzien and a series of tests made in Japan. From the latter test series, 104 specimens are selected, with shear span ratios ranging from 1.0 to 3.0. Summary equations are developed by statistical methods. This new model takes into account a greater number of parameters than previous models. The hysteresis loops generated from these equations are in better agreement with the test data than has been the case with previous models. In particular, the new model is compared with one developed previously by Atalay and Penzien.

● 6.6-98 Kaya, I. and McNiven, H. D., **Investigation of the nonlinear characteristics of a three-story steel frame using system identification,** *UCB/EERC-78/25,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1978, 93.

This study describes two mathematical models designed to predict the responses to seismic disturbance of a three-story steel frame. This paper is an extension of previously reported work on the construction of mathematical models to predict the linear response of the frame. This study considers only the manner by which the previous models can be extended to accommodate nonlinear responses. This extension consists of accounting for changes in the damping coefficients when the amplitudes of motion are large, and for yielding by including the hysteretic behavior of the ends of the members. An important decision was to model the hysteretic relationship between the

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bending moments and the rotations at the ends of the members. It was decided to allow the relationship to be bilinear, partly because this form has not been used before and partly because it was considered simplest.

With the introduction of hysteretic material behavior, three new parameters are added to the eight carried over from the linear model, so that the new nonlinear models contain eleven parameters. For economy, two of the parameters in each model were fixed, leaving the remaining nine to be determined from optimization. The difference between the two models is in the choice of which two of the parameters are fixed. In the first, the values of the damping parameters are fixed by giving them the values found after optimization for the linear model. In the second model, the parameters representing the yield moments in the bilinear model are fixed, one each for the columns and girders, and the damping parameters are found from optimization. Both of the models predict the experimental time histories of the floor translations and joint rotations very accurately.

● 6.6-99 Raghavan, K. S. and Rao, S. S., **Influence of elasto-plastic transition on the inelastic response of beams and plates,** *Journal of Applied Mechanics, ASME,* **45,** *3,* Sept. 1978, 521–526.

This paper considers the significance of the elastoplastic transitional state in the dynamic response of Euler beams and thin plates. The study is based on a comparative evaluation of the responses predicted by two independent approaches that use (1) the stress-strain relation and basic plasticity theory, and (2) the moment-curvature relation, assuming the shape factor to be unity. Responses are evaluated by finite-element idealization followed by numerical integration. It is found that the simplified model, based on moment-curvature relationships, significantly underestimates the response for longer durations of the applied load.

6.7 Nondeterministic Dynamic Behavior of Nonlinear Structures

● 6.7-1 Iyengar, N. R. and Iyengar, J. K., **Stochastic analysis of yielding system,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM2,* Proc. Paper 13693, Apr. 1978, 383–398.

The probability distribution of the instantaneous incremental yield of an inelastic system is characterized in terms of conditional probability and average rate of crossing. Detailed yield statistics of a single degree-of-freedom elastoplastic system under Gaussian white noise are obtained for nonstationary and stationary responses. This analysis indicates that the yield damage is sensitive to viscous damping. The spectra of mean and mean square damage rates are presented.

● 6.7-2 Kisliakov, S., **Stochastic investigation of gravity dams subjected to earthquake loading,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-54, 1978, 403–409.

The motion of a gravity dam is investigated under wide-band earthquake loading which is approximated by band-limited white noise. The dam is considered to be a multidegree-of-freedom system, and a set of independent differential equations for the generalized coordinates is obtained. A formula is presented for the mean square of the k-th generalized coordinate, and some conclusions are drawn. The degree of expected earthquake loading and the influence of different natural frequencies on the dam are analyzed. The spectral density of the k-th generalized coordinate is also investigated.

● 6.7-3 Stott, S. J. and Masri, S. F., **Random vibration of a nonlinear two-degree-of-freedom oscillator,** *CE 78-08,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Sept. 1978, 95.

An analytical and experimental investigation is made of the dynamic response of a nonlinear two degree-of-freedom oscillator that models some of the basic phenomena in the response of complex nuclear power plant systems to dynamic environments. An approximate analytical solution is obtained for the stationary response of the system when subjected to stationary random excitation. The findings are verified by experimental measurements performed with an electronic analog computer and numerically simulated solutions generated with a digital computer. Results are given for the power spectral density and root-mean-squared level of the response. The effects of various system parameters on the response of the nonlinear system are determined.

● 6.7-4 Stott, S. J. and Masri, S. F., **Dynamic excitation of a single-degree-of-freedom hysteretic system,** *CE 78-09,* Dept. of Civil Engineering, Univ. of Southern California, Los Angeles, Sept. 1978, 97.

An analytical investigation is made of the dynamic response of two special classes of nonlinear hysteretic oscillators that model some of the basic phenomena in the response of complex nuclear power plant systems to dynamic environments. Numerical studies are presented as well as approximate analytical solutions for the response of the nonlinear oscillators under harmonic and random excitation. The effects of various system parameters are evaluated and the range of validity of the approximate solutions is determined.

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● 6.7-5 Shtol, A. T., **Dynamic stability of compressed and bent rods under random two-dimensional excitations (such as seismic)**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-17, 1978, 125-128.

This paper examines thin-walled structures and obtains averaged equations of motion for such structures. The earthquake effect is presented as a random, time-varying two-dimensional process. The horizontal and vertical components of the seismic effect are regarded as stationary independent random functions of time with known statistical characteristics. A rod structure is discussed, the design model of which can be presented as an elastic bar of a constant cross section and rigidity with a concentrated mass at the end.

● 6.7-6 Karasudhi, P., Wu, C.-C. and Takemiya, H., **Probabilistic solution to hysteretic systems subjected to earthquakes**, *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection*, 110-120. (For a full bibliographic citation see Abstract No. 1.2-3.)

Nonlinear terms in the Fokker-Planck equation of bilinear hysteretic systems are replaced by linear terms, each containing a single coefficient which is determined by minimizing a properly weighted mean square difference between two corresponding nonlinear and linear terms. This study is carried out first for single degree-of-freedom systems and then is extended to multidegree-of-freedom systems. The statistical seismic response of these systems, involving a complex eigenvalue problem, is obtained. In addition, a linearization method with two coefficients for each corresponding pair of nonlinear and linear terms in the Fokker-Planck equations is studied.

● 6.7-7 Fujita, T. and Shimosaka, H., **Probabilistic analysis of nonlinear seismic response for liquid storage tank-supporting leg systems** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 144, Nov. 1978, 1145-1152.

This paper deals with a probabilistic analysis and experiments of the nonlinear seismic response and fatigue failure of liquid storage tank supporting-leg systems. These systems are models for short-leg-supported liquid storages in nuclear power plants and chemical plants and for elevated tanks, such as fuel tanks and cooling water tanks for diesel engines. The sinusoidal excitation experiment shows that the response tank displacement becomes large in the case of resonance of the overall system where the liquid works as a simple mass and that the damping depends upon the response magnitude. The dynamic model for this system is identified as a nonlinear single degree-of-freedom system which contains an equivalent mass for the liquid and a response tank velocity-dependent damping. The probabilistic analysis of the seismic response is carried out, employing this dynamic model and an artificial ground acceleration which is a nonstationary Gaussian shot noise. The nonstationary joint probability density of the tank displacement and velocity is obtained by solving approximately the unstable Fokker-Planck equation. The nonstationary probability density of the peak strain in the supporting legs is derived by using the algebraic relationship between the tank displacement and the supporting-leg strain. The expected fatigue damage accumulated in the supporting leg is analyzed based on Miner's law. Experiments are carried out to examine the analytical result, including a fatigue test of the supporting legs. Good correlation between the analytical and experimental results is obtained.

● 6.7-8 Wen, Y.-K., **Stochastic seismic response analysis of hysteretic multi-degree-of-freedom structures**, *Probabilistic Analysis and Design of Nuclear Power Plant Structures*, 21-37. (For a full bibliographic citation, see Abstract No. 1.2-17.)

The analytical study of random vibrations 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 it could be very costly. This paper presents an empirical analytic method for a yielding MDF system. The method is based on a substitute structure (SS) concept in which the SS parameters are determined from an empirical analysis of single degree-of-freedom systems. 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 (R. C. 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., one second of execution time on the IBM 360-75 system for an eight-story steel frame.

● 6.7-9 Sakamoto, J., Kohama, Y. and Yamazaki, T., **On the dynamic behavior of braced steel frames** (in Japanese), *Transactions of the Architectural Institute of Japan, 270*, Aug. 1978, 43-52.

This paper clarifies the inelastic dynamic behavior of steel frames with bracings that have degrading restoring-force characteristics. Discussed are (1) The reasonable lateral force bearing ratios of bracings and frame in the plastic design process from the viewpoint of the pertinent dynamic characteristics; (2) The stationary random response

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of single-story braced frames subjected to white noise excitation by the equivalent linearization technique; and (3) The dynamic behavior of five-story, three-bay braced frames subjected to nonwhite noise excitation by the Monte Carlo simulation technique.

● 6.7-10 Udagawa, K., Takanashi, K. and Tanaka, H., **Restoring force characteristics of H-shaped steel beams under cyclic and reversed loadings (Part I: rotation capacity of plastic hinge under cyclic loads at constant deflection amplitudes)** (in Japanese), *Transactions of the Architectural Institute of Japan, 264,* Feb. 1978, 51-59.

Among the various failure patterns of steel structures subjected to cyclic loading are the following: (1) strength deterioration of a structure or its members as a result of excessive deformation, and (2) fracture of members caused by low-cycle plastic fatigue. In order to avoid these kinds of failures and to evaluate damage to structures from various external forces, the energy-absorption capacity and restoring force characteristics of structures or members under cyclic loading were investigated quantitatively. A series of tests was conducted to determine the restoring force characteristics of H-shaped steel beams under cyclic and reversed loadings, particularly beams of sizes which are expected to fail because of local and lateral buckling. The purposes of the experiment were: (1) to determine a critical deflection amplitude in constant deflection amplitude cyclic loadings up to which load-deflection hysteresis loops are stable; this critical deflection depends on various ratios of deflection amplitudes, lateral bracing spacings, material properties, and section properties of the beams; (2) to represent stable hysteresis loops in mathematical expressions deriving from experimental data; (3) to inquire into the relation between a maximum deflection amplitude and strength deterioration when beams are cycled by a random deflection; and (4) to obtain the relationship between strength deterioration and deflection amplitude in various ratios of deflection amplitudes in the range at which hysteresis loops become unstable under constant deflection amplitude cyclic tests, and, based on the results, to evaluate the strength deterioration of beams subjected to random deflection.

● 6.7-11 Udagawa, K., Takanashi, K. and Tanaka, H., **Restoring force characteristics of H-shaped steel beams under cyclic and reversed loadings (Part II: strength deterioration of beams under random deflections)** (in Japanese), *Transactions of the Architectural Institute of Japan, 265,* Mar. 1978, 45-52.

If the strength deterioration of beams subjected to random deflections can be predicted from the results of constant deflection amplitude tests, it may be possible to predict beam failure during an earthquake. This paper examines the deterioration of beam strength when the beams are subjected to various ratios of deflection amplitude in the unstable deflection amplitude region. Based on these data, ways of evaluating the strength deterioration of beams subjected to random deflections are shown.

● 6.7-12 Matsushima, Y., **Random response of single-degree-of-freedom system with slip hysteresis** (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 91-97.

This paper concerns the analytical estimation of the probabilistic properties of the stationary random response for a single degree-of-freedom system with slip hysteresis when subjected to Gaussian white noise excitation. The plastic stiffness of the slip hysteretic system has an arbitrary magnitude. The expressions obtained are examined by digital simulation. It is found that the analytical solution of the root-mean-square displacement coincides with the corresponding experimental result with sufficient accuracy, and that the theoretical root-mean-square plastic deformation provides good information about its general tendency, although it does not always bring about a satisfactory quantitative prediction in a strict sense. In addition, it is concluded that the theoretical values of the expected accumulated plastic deformation agree well with the simulated values over a wide range of related parameters.

● 6.7-13 Roberts, J. B. and Yousri, S. N., **An experimental study of first-passage failure of a randomly excited structure,** *Journal of Applied Mechanics, ASME,* 45, *4,* Dec. 1978, 917-922.

Some experimental measurements of the mean and standard deviations of the first-passage time of randomly excited cantilevers are presented. It is shown that these results can be predicted satisfactorily by using a theoretical method based on the energy envelope of the structure, together with information on the energy loss per cycle. This information can be derived either from free decay tests or from data on specific damping factors. The prediction technique does not require the damping forces to be modeled in explicit form and enables nonlinear damping effects to be readily incorporated. Some predicted nonlinear effects are confirmed by the experimental results.

● 6.7-14 Roberts, J. B., **The response of an oscillator with bilinear hysteresis to stationary random excitation,** *Journal of Applied Mechanics, ASME,* 45, *5,* Dec. 1978, 923-928.

By applying the technique of stochastic averaging, a simple analytical result is obtained for the joint distribution of the displacement and velocity of a bilinear oscillator excited by a stationary random process. A comparison of theoretical results deduced from this distribution with corresponding digital simulation results shows that the

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theory is accurate in circumstances where the response is narrow-band in nature.

● **6.7-15** Spanos, P.-T. D., **Stochastic analysis of oscillators with non-linear damping,** *International Journal of Non-Linear Mechanics,* 13, *4,* 1978, 249–260.

The response of a class of oscillators with nonlinear damping to stochastic excitation is considered. A partial differential equation which describes approximately the probability density function of the response amplitude is derived. The stationary and nonstationary solutions of this equation are examined. The soundness of the method is tested by comparing the solutions generated by its application to problems with known solutions. The Van der Pol and Rayleigh oscillators are included in the example problems studied.

● **6.7-16** Ibrahim, R. A., **Stationary response of a randomly parametric excited nonlinear system,** *Journal of Applied Mechanics, ASME,* 45, *4,* Dec. 1978, 910–916.

This paper presents a review of three truncation schemes for the problem of the infinite hierarchy of moment equations and an investigation of the stationary response of a nonlinear system under a broad-band random parametric excitation. The validity of the truncation methods is discussed together with the conditions for preservation of moment properties. One of these schemes is employed to truncate the dynamic moment equations of a nonlinear single-degree-of-freedom system subject to a broad band random parametric excitation. The influence of inertia, stiffness, and damping nonlinearities is discussed, and closed-form solutions are obtained for each case. The preservation of the response moment properties is confirmed for certain solutions while it fails for the remaining solutions. The invalidity of these solutions is not necessarily attributed to the inaccuracy of the truncation method used since it may be a result of the fact that the system may not be able to achieve a stationary response.

● **6.7-17** Maltez M., H., **Deterministic and non-deterministic comparative study on the response of structures,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* 14, Dec. 1978, 299–314.

The responses of multidegree-of-freedom systems are compared by applying random vibration theory to deterministically obtained responses. Two types of earthquake accelerograms were generated by a digital computer. These accelerograms represent narrow-band excitation as well as wide-band excitation. The narrow-band excitation was selected to study the influence of such excitation on structural response.

● **6.7-18** Popov, E. P. and Petersson, H., **Cyclic metal plasticity: experiments and theory,** *Journal of the Engineering Mechanics Division, ASCE,* **104**, *EM6,* Proc. Paper 14257, Dec. 1978, 1371–1388.

Stress-strain curves are presented for random inelastic cyclic loadings of 2-in. (51-mm) diameter, thin-walled ASTM A106 seamless steel tubes subjected to uniaxial and torsional experiments. The mechanical properties of the selected steel resemble those of the A36 steel widely used in building construction. The experiments simulate the extreme conditions which may occur in some elements of structural steel frames during severe earthquakes. The uniaxial cyclic tests correspond to the conditions which may develop in the flanges of beams, and the torsional tests simulate those in the panel zones of the beam-column joints. Employing the effective stress and the effective plastic-strain invariants and a hereditary concept, a procedure is described for using the experimental results from uniaxial tests for obtaining constitutive relations for generalized loadings, including complete load reversals. The calculated results are compared with experimental results and good agreement is shown.

● **6.7-19** Spanos, P.-T. D., **Hysteretic structural vibrations under random load,** *EMRL 1125,* Engineering Mechanics Research Lab., Univ. of Texas, Austin, June 1978, 27.

The nonstationary and stationary response of a lightly damped hysteretic structural system to a white random load is considered. The hysteretic behavior is examined by using a model consisting of an infinite collection of elasto-plastic elements, the yield loads of which are probabilistically specified. An equivalent linear system is constructed for the original hysteretic system. This system is used to obtain approximate solutions for the statistics of the response amplitude. The analytical results are used to perform a variety of parametric studies.

6.8 Soil-Structure Interaction

● **6.8-1** Wong, H. L. and Luco, J. E., **Dynamic response of rectangular foundations to obliquely incident seismic waves,** *Earthquake Engineering and Structural Dynamics,* 6, *1,* Jan.-Feb. 1978, 3–16.

A study is made of the harmonic response of a rigid massless rectangular foundation bonded to an elastic half-space and subjected to the action of both external forces and obliquely incident plane seismic waves. The associated mixed boundary value problem is discretized and solved numerically. The results indicate that the angle of incidence of the seismic wave has a marked effect on the nature and magnitude of the foundation response.

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● 6.8-2 Bielak, J., **Dynamic response of non-linear building-foundation systems,** *Earthquake Engineering and Structural Dynamics,* **6**, *1*, Jan.-Feb. 1978, 17–30.

The steady-state response of a bilinear hysteretic structure supported on the surface of a viscoelastic halfspace is analyzed. The equivalent linearization method is used to solve the equations of motion, and simplified approximate formulas are obtained for the fundamental resonant frequency of the system and for an effective critical damping ratio. Numerical results indicate that for nonlinear hysteretic structures compliance of the soil foundation may lead to larger displacements than would occur if the base were rigid. This behavior differs from that generally observed for linear systems, for which the effect of soil-structure interaction is to reduce the rigid-base response.

● 6.8-3 Gutierrez, J. A. and Chopra, A. K., **A substructure method for earthquake analysis of structures including structure-soil interaction,** *Earthquake Engineering and Structural Dynamics,* **6**, *1*, Jan.-Feb. 1978, 51–69.

A general substructure method for analysis of structural response to earthquake ground motion, including the effects of structure-soil interaction, is presented. The method is applicable to complex structures idealized as finite element systems, with the soil region treated as either a continuum, for example as a viscoelastic halfspace, or idealized as a finite element system. The halfspace idealization permits reliable analysis for sites where essentially similar soils extend to large depths and there is no rigid boundary such as soil-rock interface. For sites where layers of soft soil are underlain by rock at shallow depth, finite element idealization of the soil region is appropriate. Although the direct and substructure methods would lead to equivalent results, the latter provides the better alternative, because treating the free field motion directly as the earthquake input eliminates the deconvolution calculations and the related assumptions regarding type and direction of earthquake waves required in the direct method. Spatial variations in the input motion along the structure-soil interface of embedded structures or along the base of long surface-supported structures are included in the formulation.

The substructure method is computationally efficient because the two substructures—the structure and the soil region—are analyzed separately; more important, this method permits taking advantage of the fact that response to earthquake ground motion is essentially contained in the lower few natural modes of vibration of the structure on a fixed base.

● 6.8-4 Simpson, I. C., **On the interaction of Rayleigh surface waves with structures,** *Earthquake Engineering and Structural Dynamics,* **6**, *3*, May-June 1978, 247–263.

A two-dimensional soil-structure interaction analysis is carried out for transient Rayleigh surface waves incident on a structure. The structure is modeled by a three degree-of-freedom rigid base mat to which is attached a flexible superstructure modeled by a single mass-spring system. The structural responses to a Rayleigh wave train are compared with those that would have been obtained if the free-field acceleration-time history had been applied as a normally incident body wave.

The results clearly exhibit the frequency filtering effects of the rigid base mat on the incident Rayleigh waves. It is shown that if seismic excitation of a structure is, in fact, due to Rayleigh surface waves, then an analysis assuming normally incident body waves can considerably overestimate structural response, both at base mat level for horizontal and vertical motions and for vertical oscillations of the superstructure. However, in the examples considered here, relatively large rocking effects were induced by the Rayleigh waves, thus giving maximum horizontal accelerations in the superstructure that were of comparable magnitude for Rayleigh and normally incident body waves.

● 6.8-5 Taylor, R. E., **A two degree of freedom model for the dynamics of offshore structures,** *Earthquake Engineering and Structural Dynamics,* **6**, *4*, July-Aug. 1978, 331–346.

To understand the structural dynamics of deepwater gravity platforms, the dynamic response of a linear two degree-of-freedom spring-mass-damper system is studied. The mathematical model represents the dynamic interaction between structure and foundation. Attention is paid to the influence of wave force distribution. Transfer functions are obtained for the response to sinusoidal waves, and resonant magnification factors are plotted for a range of structural and loading parameters. It is concluded that the response of this simple idealization is not straightforward.

● 6.8-6 Byrne, P. M. and Nathan, N. D., **Earthquake induced overturning moments and their effects,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-12, 1978, 85–92.

A method of analysis for predicting the earthquake-induced rocking motion of a structure on a flexible foundation soil is presented. The soil is represented by a bed of elastic-plastic springs allowing the strength of the soil as well as its stiffness to be incorporated in the analysis. Application of the method indicates: (1) the maximum-induced overturning moment depends primarily on the strength of the soil and whether the foundation is free to lift from the soil and (2) overturning of tall buildings as a result of soil failure is unlikely to occur.

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● 6.8-7 Veletsos, A. S., **Soil-structure interaction for buildings during earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 111-133.

After a brief review of the principal effects of soil-structure interaction on the response of structures subjected to ground motions, a simple practical procedure is presented for evaluating these effects. The procedure utilizes standard response spectra for fixed-base systems. A brief account also is given of how the concepts underlying this approach have been used recently in the formulation of recommended seismic design provisions.

● 6.8-8 Ungureanu, N., **Seismic analysis of gravity dams taking into consideration the deformation of foundation rock,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-53, 1978, 395-402.

A method for analyzing gravity dams under seismic motion is presented. The interaction between the dam and the foundation rock is considered. A dynamic analysis for the dam is conducted by the finite element method. The interaction effect is introduced at the contact surface level by assimilating the foundation rock to an elastic half-plane. Equations of motion for the dam in interaction with the foundation rock are derived, and stiffness matrices are presented for the support and the dam-foundation systems.

● 6.8-9 Kaufman, B. D. and Shulman, S. G., **Seismic vibrations of a multimass system on an elastic base,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-07, 1978, 47-52.

The two-dimensional seismic vibrations of a linear-elastic multimass structural model with a base idealized by a homogeneous isotropic elastic halfplane is studied. The vibrations are described by a set of ordinary differential equations; and the motion of the base, by Lame equations. Displacements of the base caused by the interaction load are determined from using the Lamb method, which is solved using Laplace and Fourier transformations. The problem is reduced to a set of Volterra integral equations and solved numerically using a computer. The results obtained can be used to evaluate the inertia-rigidity and damping effects of the base on the vibrations of a multimass system.

● 6.8-10 Isenberg, J. and Vaughan, D. K., **Three-dimensional nonlinear analysis of soil-structure interaction in a nuclear power plant containment structure,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 911-920.

The soil island approach to soil-structure interaction is applied to the SIMQUAKE 1 series of explosive field tests designed to simulate earthquake ground motion effects on model nuclear containment structures. These tests indicate strong nonlinear response of the model structures. The three-dimensional, nonlinear finite element computer program TRANAL is used to simulate the response of a 1/12 scale model containment structure in SIMQUAKE 1a. Results are compared with measured data.

● 6.8-11 Alarcon, E. *et al.,* **Boundary methods in soil-structure interaction,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 921-932.

A general theory that describes the boundary integral equation method approximation in steady-state elastodynamics is developed. Constant and linear elements in plane problems are presented and results are compared.

● 6.8-12 Warburton, G. B., **Ground excitation of tower structures—a continuum approach,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-11, 1978, 77-84.

For parametric studies, idealization of a tower structure as a uniform vertical beam attached at its base to a mass, representing the foundation, and use of known solutions for the horizontal translation and rocking modes of a rigid foundation on an elastic halfspace are simpler than the conventional approach, which idealizes the structure as a multidegree-of-freedom system. The effect of various parameters on the response to a free-field harmonic acceleration at the soil-structure interface is studied. The implications of large dynamic magnitude factors for structural response to earthquakes are discussed.

6.8-13 Kausel, E. *et al.,* **The spring method for embedded foundations,** *Nuclear Engineering and Design,* **48,** *2&3,* Aug. 1978, 377-392.

The paper presents simplified rules to account for embedment and soil layering in the soil-structure interaction problem to be used in dynamic analyses. The relationship between the spring method and a direct solution (in which both soil and structure are modeled with finite elements and linear members) is first presented. It is shown that, for consistency of the results obtained with the two solution methods, the spring method should be performed in three steps. The first two steps require finite element methods, which would make the procedure unattractive. It is shown, however, that good approximations can be obtained on the basis of one-dimensional wave propagation theory for the solution of step 1 and correction factors for modifying for embedment the corresponding springs of a surface footing on a layered stratum for the solution of step 2. Use of these rules not only provides remarkable agreement with the results obtained from a full finite element analysis but results in substantial savings of computer execution and storage requirements. This frees the engineer to perform extensive studies, varying the input properties over a wide range to account for uncertainties, particularly with respect to the soil properties.

● **6.8-14** Iwasaki, T. and Kawashima, K., **Seismic analysis of a highway bridge utilizing strong-motion acceleration records,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1211–1222.

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 system is investigated based on 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 induced by earthquakes with magnitudes of 7.5 and 6.6, respectively, and two induced by the aftershocks of these earthquakes. The maximum accelerations of the two earthquakes were 186 and 438 gals, respectively, on the ground surface, and 310 and 230 gals, respectively, on the pier top. Analyses of frequency characteristics of the motions showed that the predominant frequencies of the pier-foundation system were always very similar to the fundamental natural frequency of the subsoil. Analyses of microtremors measured at the sites reveal 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 system; the subsoil and pier-foundation are assumed 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 compared with the measured records, and good agreement is obtained.

● **6.8-15** Petrovski, J., **Influence of soil-structure interaction effects on dynamic response of large panel prefabricated buildings,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1269–1277.

Existing methods for structural dynamic response analysis often use the assumption of the structural base fixed in the soil media, considering the soil to be rigid and nondeformable. Experimental results from full-scale forced vibration studies of rigid structures show that this assumption has little physical justification. Mathematical models are formulated of large panel prefabricated buildings, one 5-story and one 22-story, using dynamic properties obtained from a full-scale forced vibration study. Up to a 50% increase of the base shear is obtained by comparing the results from the response analysis of the fixed and flexible base models of the buildings. It is concluded that the influence of soil-structure interaction ought to be considered in the construction of large panel prefabricated buildings and similar rigid structures, particularly because of the significant increase in lateral forces not considered in existing seismic design codes.

● **6.8-16** Warburton, G. B., **Soil-structure interaction for tower structures,** *Earthquake Engineering and Structural Dynamics,* **6,** *6,* Nov.-Dec. 1978, 535–556.

The soil-structure system is modeled as a uniform vertical beam which terminates in a base or foundation mass attached to the surface of an elastic halfspace. Using known force-displacement relationships for the coupled vibrations of a rigid disc on an elastic halfspace, the natural frequencies and response to a transverse harmonic force applied at the tip of the beam are determined through a continuum approach. The problem effectively reduces to that of a beam with frequency-dependent boundary conditions. A parametric study shows that changes in the three ratios (Young's modulus for the beam to that for the halfspace, the radius of the base mass to the length of the beam, L, and the second moment of area of the beam cross section/L^4), cause large variations in the maximum response, which, because of interaction, can be considerably smaller or larger than that for a comparable fixed-base cantilever beam. This dynamic behavior can be explained by considering the variation of natural frequencies, mode shapes, and modal damping factors with these ratios. A brief study of the response of the structure to a free-field harmonic acceleration applied at the soil-structure interface, suggests that interaction depends upon the material and geometric properties of the system rather than on the nature of the excitation.

6.8-17 Seed, H. B. and Lysmer, J., **Soil-structure interaction analyses by finite elements—state of the art,** *Nuclear Engineering and Design,* **46,** *2,* Apr. 1978, 349–365.

This paper summarizes the current capability for evaluating soil-structure interaction effects during earthquakes using finite element procedures. A concise summary of methods and their capabilities and relative costs is presented. It is suggested that finite element procedures are excellent for use in the design of nuclear plants, especially

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for embedded structures. Computed results are compared with those recorded in a nuclear plant during a strong-motion earthquake. It is concluded that when the methods are used in conjunction with good engineering judgment and their limitations are recognized, they provide evaluations of response with a level of accuracy entirely adequate for engineering design.

● 6.8-18 Savinov, O. A. and Uzdin, A. M., **Consideration for structure-foundation interaction within the limits of seismic stability linear-spectral theory,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-18, 1978, 131-138.

● 6.8-19 Medvedeva, E. S., **The dependence of the intensity of the seismic effect of the construction from the dimension of its depth into soil,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-06, 1978, 33-37.

Interaction between the soil and the subsurface part of a structure is influenced by the horizontal and vertical propagation of seismic waves. The horizontal inertial force depends upon the fall angle (longitudinal or transversal) of the wave and upon the corresponding coefficients of refraction. Calculations are performed for six types of construction.

● 6.8-20 Venancio F., F. and Sacoda, C., **A two parameter foundation model for soil-structure interaction,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-16, 1978, 115-122.

A finite element formulation based upon the Galerkin method is used in the development of stiffness and consistent mass matrices for the dynamic analysis of structures supported on a two-parameter elastic foundation. The behavior of the foundation is governed by the Vlasov Leont'ev theory. Natural frequencies of a beam on an elastic foundation obtained with this formulation present very good agreement with the exact ones. The beam-elastic-foundation finite element is used for the study of soil-structure interaction problems in nuclear reactors.

● 6.8-21 Evans, P. L., **The Middle East-an outline of the geology and soil conditions in relation to construction problems,** *Current Paper 13/78,* Building Research Establishment, Watford, England, Nov. 1977, 17.

This paper briefly summarizes information collated from geological maps, journals, and reports of site investigations and aggregate surveys. The first part consists of a brief geological description of each of the countries considered; the second relates the geology and soil conditions to some of the construction problems which occur in these regions.

● 6.8-22 Varadhi, S. N., Saxena, S. K. and Vey, E., **Foundation response to soil transmitted loads,** *Geotech Series 77-201,* Dept. of Civil Engineering, Illinois Inst. of Technology, Chicago, Dec. 1977, 218. (NTIS Accession No. PB 279 055)

This research deals with effects on foundation response produced by stress waves propagating from underlying soils. A circular footing was located at the surface and at different depths of burial, and a transient load was applied to the footing through the underlying soils. Stress and strain time histories were recorded by embedded gages. These records were correlated with acceleration time records of the input load and foundation response to provide a comprehensive picture of stresses and strains in a soil mass subjected to earthquake-type loading. The investigation also includes static and dynamic experiments conducted using a thin layer of compressible material buried at depths of one radius below the footing.

● 6.8-23 Karasudhi, P., Balendra, T. and Lee, S.-L., **Seismic analysis of soil-building interaction systems,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 121-132. (For a full bibliographic citation see Abstract No. 1.2-3.)

An efficient method is presented to analyze a multistory shear building resting on the surface of an elastic soil medium. Recognizing that the superstructure exhibits classical normal modes, the problem is reduced to the solution of two coupled integro-differential equations. Using these equations, it is found that the first few modes produce good approximations to the exact seismic response of the total system.

● 6.8-24 Birulya, D. N., **Seismic response of soil-building system by the finite element method,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-17, 1978, 123-130.

The soil profile between the bedrock and superstructure (a five-story building) is considered to be a two-dimensional finite element (a constant strain triangle). The mass of the building is 3% of the mass of the soil. The seismic analysis is carried out by step-by-step integration using an unconditionally stable linear acceleration method. For all cases investigated (soft soil and firm, homogeneous and inhomogeneous), the building moves as a rigid body. The seismic response shows a combination of the rotational motion of the building superimposed upon the lateral motion of underlying soil.

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● 6.8-25 Dumanoglu, A. A., **Theoretical and experimental studies for the earthquake analysis of multistory frames on elastic foundations** (Elastik zemine oturan cok katli cercevelerin deprem hesabi icin teorik ve deneysel incelemeler, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, 5, 20, Jan. 1978, 8-51.

The object of this study was to find the extent to which foundation elasticity influences the dynamic response of multistory frames during an earthquake. To simulate the effect under laboratory conditions, three models were constructed in which foundations (ground) and structures were "combined." Two of these were combined plane frames with ground elasticity moduli of $E_f = 45/cm^2$ and $E_f = 405\ kg/cm^2$, respectively. The third was an asymmetric space frame with a ground elasticity modulus of $E_f = 45\ kg/cm^2$.

Analysis was in two stages. In the first stage, the resonance behavior of the combined models was analyzed. In the second stage, the dynamic response was analyzed. Both theoretical and experimental analyses were performed in these stages.

A nondimensional analysis of the reduction of the first three natural frequencies by the foundation medium was made by comparing the results of the rigidly fixed and combined structures. In the dynamic response analysis, the combined models were subjected to the recorded ground accelerations of the El Centro, Koyna, and Parkfield earthquakes as well as to two components of the San Fernando earthquake.

● 6.8-26 Weidlinger Assoc., **Nonlinear soil-structure interaction**, *EPRI NP-945*, Electric Power Research Inst., Palo Alto, California, Dec. 1978, 225.

This report presents the results of research on the modeling of the constitutive properties of soil and soil-structure interaction for nuclear power plants during earthquakes. The models developed are general and can be used to simulate a three-dimensional structural geometry, nonlinear site characteristics, and arbitrary input ground shaking. This research extends the cap family of constitutive models of soils to include earthquake effects. Cyclic hysteresis in shear is accounted for by: (1) as an interim step, adding viscoelastic behavior resulting in hysteresis during cyclic loading which is relatively insensitive to moderate changes in strain rate; and (2) permanently amending the cap model to include nonlinear kinematic hardening in shear. Also, the cap model is extended to include the effects of pore fluid on the seismic response of soils. In addition, the soil island approach to soil-structure interaction is adapted for seismic problems. The sensitivity of seismically induced soil-structure interaction to the size of the soil island is investigated. Application of the soil island approach is made to the SIMQUAKE I series of explosive field tests designed to simulate earthquake ground motion effects on model nuclear containment structures. Two- and three-dimensional finite element simulations of the tests are performed and results are compared with measured data. Pretest predictions of the SIMQUAKE II event are made using two- and three-dimensional nonlinear soil island models. The three-dimensional model yields lower response than the two-dimensional model.

● 6.8-27 Gyoten, Y. *et al.*, **Study on soil-pile interaction in vertical vibration**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 48, Nov. 1978, 377-384.

This paper deals with a theoretical study of soil-pile interaction. The pile is assumed to be vertical and elastic. The soil is considered to be a linear viscoelastic layer with hysteretic damping. First, the vibration of only the soil layer is solved by means of the elastic wave theory. Assuming perfect contact between the pile and the soil layer, the vertical deformation at the circumference of the pile and the resistance force from the soil layer can be obtained. This resistance force is evaluated by examining the shear stress at the circumference of the pile. The pile response to a harmonic load is obtained in a closed form and used to define stiffness and damping at the level of the pile head. It is found that the response of the floating pile, for which the resistance force at the pile tip is neglected, is affected a great deal by the soil layer. The resistance factor of pile groups, which includes the effect of other piles, differs from that of a single pile above resonance. The response of pile groups above resonance is affected significantly by the dimensionless distance between piles and by the wave velocity ratio of the soil layer to the pile.

● 6.8-28 Satake, M. and Asano, T., **On the response characteristics of caisson-piers during earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 49, Nov. 1978, 385-392.

Observations are continuing of earthquake motions at depths of 25 m and 59 m on caissons, piers, and girders for two bridges, the Iinogawa Bridge and the Hirosegawa Aqueduct Bridge, in the Miyagi Prefecture, Japan. Most of the records concern JMA intensities I to III, except for one record of JMA intensity IV obtained at the Hirosegawa bridge. This paper reports the response characteristics of the caissons and piers and special emphasis is placed on the effects of epicentral distance and the influence of the ground and the girders.

The results can be summarized as follows: (1) The periods of maximum acceleration in the horizontal direction are 0.1 sec to 1.0 sec in the caissons and relatively constant at the top of the pier with fixed support. For a support that is movable, the periods in the transverse

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direction are longer for longer epicentral distances and those periods in the longitudinal direction are slightly longer. This difference may be caused by the influence of the girders. (2) The ratio of the maximum acceleration at the top of the pier to the base of the caisson is affected by the epicentral distance. In the fixed direction of support, the longer the epicentral distance, the greater the ratio. (3) By analyzing the transfer function, which is the ratio of the Fourier spectral amplitude of acceleration at the top of the pier to the base of the caisson, it is found that the period corresponding to the maximum ratio is comparatively constant in every earthquake and that the ratio itself varies with epicentral distance. This may be caused by the upper structure having a larger amplification for a comparatively long period. (4) By using a running spectrum analysis, it is found that the most predominant periods corresponding with the maximum acceleration in the ground, at the base of the caisson, at the top of the pier with fixed support, and at the girder vary with time. It also is noted that, for the pier having movable support, such periods in the base of the caisson and at the top of the pier do not vary with time in the longitudinal direction. Thus, it is considered that, in the movable direction, a caisson and pier behave in a similar manner but that, in the fixed direction, the motions at the base of the caisson and at the top of the pier are affected strongly by those of the ground and girder, respectively.

● 6.8-29 Masao, T., **Soil structure interaction analyses for cylindrical rigid body** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 50, Nov. 1978, 393-400.

A modified theory for a cylindrical rigid body in soil is used to derive a solution for a distant base rock model. In this model, the radiational wave passes under the bottom of the base rock. Frequency responses, resonant frequencies, and equivalent damping factors are calculated and compared with the results of experiments.

● 6.8-30 Harada, T. and Kubo, K., **Dynamic (complex) stiffness and vibration of embedded cylindrical rigid foundation**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 51, Nov. 1978, 401-408.

An approximate theory is presented for the calculation of the dynamic stiffness of a coupled swaying and rocking motion of a cylindrical rigid foundation embedded in a soil stratum overlying a much stiffer rock-like material. The stiffness is influenced by shear modulus of the soil, soil frequency, foundation slenderness, hysteretic damping, and Poisson's ratio. As a special case, the dynamic stiffness previously obtained by Tajimi is considered. Comparison of the theory with experiments indicates the potential capability of the theory and clearly demonstrates the need to consider the effect of the vibration of the surface soil stratum.

● 6.8-31 Iwatate, T., Kokusho, T. and Ooaku, S., **Seismic stability of embedded tank** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 122, Nov. 1978, 969-976.

To clarify experimentally and analytically the dynamic behavior of embedded tanks during earthquakes, vibration tests on a model tank in a model ground were carried out by means of a shaking table and considering the nonlinear properties of the ground, a computer program for a complex response analysis of an axisymmetric soil-structure system combined with the equivalent linear method has been developed. The utility of the method was verified by the experimental results.

For the vibration test, a brass tank model was used. The dimension of the model ground of fine dry sand was 1.2 m in length, 0.8 m in width and 1.0 m in depth. Various kinds of random waves simulating actual earthquakes were applied to the embedded model tanks. The following results are presented. Comparing the dynamic motions of the tank to the surrounding ground, the acceleration amplitudes and the vibration models coincide well with each other. The embedded tank moved predominantly in a shearing mode at the resonant frequency. The model ground exhibited strongly nonlinear properties from a low shear strain level. The nonlinear properties of the ground had strong effects on the acceleration responses and the strains of the tank.

In the complex response analysis, the model tank and the surrounding ground were simulated by thin cylindrical shell elements and axisymmetric solid elements, respectively. The numerical results are compared with the experimental results. A satisfactory agreement between the experimental results and the numerical results was obtained.

● 6.8-32 Kogarumai, M., Hojo, S. and Sakurai, Y., **Observations of dynamic behavior of anti-earthquake ductile pipes in water purification yard at Hakusan, Hachinohe City during earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 114, Nov. 1978, 905-912.

An analysis is made on the basis of data from an earthquake observation device attached to a water distribution facility currently in use. The device comprised 27 channels. Included were seven accelerometers for the water reservoir, an accelerometer for the pipe, an expansion-contraction gauge at a joint, and seismographs for the ground provided at 2 m and 27 m below the surface. The analysis was made with emphasis on the behavior of the

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earth and submerged objects. Also analyzed were correlated behaviors based on 50 earthquakes observed during May 1975 to July 1978. The following results were obtained. The behavior of a structure buried in earth and with piles driven into the earth is ruled by the behavior of the surrounding ground. The behavior of a buried pipe is ruled by the behavior of the surrounding ground. When a buried pipe is connected to a structure by means of expansion joints, the joints are subjected to expansion or contraction, the size of which is correlated with the acceleration of ground. With respect to acceleration, it is presumed that the transfer rate of amplitude from the ground to the buried object is 1:1 in the portion where the amplitude of the ground is small, and that the rate is lower in the portion where the amplitude of the ground is large. Ground acceleration, pipe acceleration, and structural acceleration have the same predominant periods, and these accelerations agree well with microtremor observations and numerical calculations. There is a trend that as the seismic intensity becomes enlarged the predominant period is lengthened slightly under the observed waveform.

● 6.8-33 Goto, Y. and Shirasuna, T., **Earthquake response characteristics of grouped underground tanks in alluvial soil layers** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 123, Nov. 1978, 977–984.

The present study deals with the earthquake response characteristics of grouped underground tanks, each one of which is a reinforced concrete cylinder and constructed closely to other tanks in alluvial layers. This paper describes a dynamic model test concerning the coupled vibration of the grouped tanks and the soil-layer system and discusses the earthquake response characteristics of the system. The reduced scale of the model is 1/150. The R.C. tanks are modeled by silicon rubber cylinders, and the soil layers are modeled by chemical gels. The soil-layers model is subjected to harmonic and random excitations on a vibration table. One-, two-, four-, and six-tank models are placed in the soil layers and tested by the same method.

The conclusions are (1) There are some differences in the resonance aspect between the one-tank model and the four- and six-tank models in relatively high frequency ranges. But, since the first resonance response of the surface layer mostly controls the earthquake response of the tanks, those differences are not significant. (2) The grouped tanks exhibit a combined force to resist the response of the surface layer. The farther each tank is placed into a soil layer, the smaller the sway amplitude of each tank becomes. (3) Each tank in the group is forced unsymmetrically by the surface layer, and the lateral overlying deformation of the cylinder is predominant. The tangential strain of the tank wall for grouped tanks is larger than that of the one-tank model. (4) The lateral deformation of each tank consists of three patterns, viz., sway, overlying by shear, and overlying by compression. In the case of grouped tanks, earthquake stresses of the tank wall should be estimated by the combination of these patterns. (5) These conclusions are applicable when the space between tanks is 0.5 D, when the tank bottom is embedded in a relatively stiff layer, and when the earthquake waves propagate vertically from the bedrock. Influences of the space and surface wave components of earthquakes should be studied in the future.

● 6.8-34 Tatsuoka, F. *et al.*, **Shake table tests on dynamic behaviors of pile foundation model in liquefying sand layers**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 84, Nov. 1978, 665–672.

A series of shaking table tests was performed on small models of grouped pile foundations embedded in saturated loose sand layers. The fundamental natural frequencies of the pile foundation models were higher when the piles were embedded in completely liquefied soil layers than when the piles were embedded in semi-elastic soil layers. The model exhibited nonstationary dynamic behavior when it was embedded in the saturated sand.

● 6.8-35 Hoshiya, M. and Yamazaki, T., **Parametric analysis on structural damage** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 103, Nov. 1978, 817–824.

The damage of a structure resulting from earthquake ground motion is analytically discussed in terms of plastic strain energy, ductility factor, and effective input energy. The model is a single degree-of-freedom bilinear hysteretic system on a homogeneous soil foundation, and the ground motion (real acceleration record) is assumed to be a vertically propagating shear wave. A sensitivity analysis is performed with randomly generated single degree-of-freedom models and foundations using the theory of quantification to evaluate the main factors influencing the damage quantities.

The following results are obtained: (1) Plastic strain energy is significantly accumulated if the structural weight is great and if the natural period is short. It is also found that input characteristics are the main factors influencing the plastic strain energy. (2) As for the ductility factor, the main factors are the natural period, the evolutionary trend of the predominant frequency of the input, and the input impedance of the wave. (3) The coefficient of input energy effectiveness is influenced mainly by the input impedance of the wave, the structural weight and the natural period. In other words, earthquake energy is more effectively absorbed by the single degree-of-freedom model provided that the foundation is solid and the structural weight is not great, and if the natural period is long. It is also found that,

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if the predominant frequency is in the lower range, the more effectively the input energy is absorbed by the structure.

● 6.8-36 Yoshida, T. and Uematsu, M., **Dynamic behavior of a pile in liquefaction sand** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 83, Nov. 1978, 657–664.

The dynamic behavior of a pile in liquefied sand was investigated experimentally and theoretically. From previous experiments, it was determined that a pile in saturated sand experienced a large transient displacement when the sand was forced to oscillate. This was considered to result from the liquefaction of the sand which induced the reduction in sand strength and the resonance of the sand layer. In order to investigate the large displacement and the mechanism of oscillation, dynamic analyses were performed for the pile and a sand layer system, taking into account the reduction in the rates of strength of the sand. The sand strength was defined in two terms: reaction force and shear strength, and the reduction rates were determined by a liquefaction test of upward permeation flow and by a dynamic triaxial compression test. The dynamic response of the pile model was calculated using data obtained from the tests. The pile model and sand layer were substituted by an oscillation system that was composed of lumped masses and springs. A linear acceleration method was used to calculate such dynamic properties as damping and stiffness matrices of the system at each step as the liquefaction progressed. The results follow: (1) The shear strength and the soil reaction force of the saturated sand decreased as a result of liquefaction. (2) The theoretical large transient response of the pile in liquefied sand showed good agreement with the experimental result. (3) It was confirmed that the large dynamic response of the pile was caused by the reduction of the strength of the sand layer and by the resonance of the pile with an external oscillating force. (4) The upward permeation flow and the dynamic triaxial compression test proved to be effective for estimating the stiffness of liquefied sand.

● 6.8-37 Hakuno, M. and Katada, T., **Dynamic behavior of underground structures during liquefaction of sand** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 82, Nov. 1978, 649–656.

The purpose of this study is to investigate experimentally the interaction of underground structures and incompletely liquefied sand by use of a sand box and a structural model. The model sand stratum is 30 cm in width, 50 cm or 100 cm in length, and about 20 cm in height. An accelerometer and a pore water pressure gauge were buried about 10 cm deep and at the center of the model ground. The accelerometer was regarded as an underground structure in this experiment. The shaking table was vibrated by stationary or transient sine wave (6 Hz). In the saturated sand stratum, the characteristics of acceleration response in the liquefaction process may be divided into three stages: pre-liquefaction, incomplete liquefaction, and complete liquefaction. In the first stage, the output wave is nearly equal to the input wave. In the second stage, as the pore water pressure rises, the output wave becomes distorted with a few peaks. These peaks are large acceleration responses caused by incomplete liquefaction of the sand. In the third stage, the model ground is completely liquefied and the acceleration response of an accelerometer buried in sand is small. In addition, in the incompletely saturated sand stratum, a very large acceleration response appears on the record for several seconds. An underground structural model was constructed and buried in a saturated sand stratum. This model is lighter than the accelerometer and its specific gravity is about 1.3. The experimental acceleration response characteristics for this model are the same as those response characteristics for the accelerometer model.

● 6.8-38 Yamahara, H. *et al.*, **Earthquake response of structure in consideration of filtering effect of foundation slab** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 69, Nov. 1978, 545–552.

This paper examines the existence of a foundation slab filtering effect using records obtained at the Hollywood Storage building during the 1971 San Fernando earthquake. The effective input motions to the building foundation were computed from the free-field motions by using a numerical filter that represents the filtering effect of a foundation slab. The theoretical foundation motions were compared with observed motions obtained simultaneously with free-field motions at a foundation. The theoretical and the observed horizontal motions were similar. To distinguish the soil-structure interaction effect from the filtering effect, the building and foundation soil were represented by a mathematical model and the transfer function of free-field motion to the foundation was presented. The theoretical transfer function was not similar to that obtained from observed records. It was found that the transfer function in which the filtering effect and soil-structure interaction were taken into consideration came closest to that of the observed record. As an example, the influence of the filtering effect on the dynamic behavior of a structure was investigated for a model PWR nuclear power building. The filtering effect was significant in a short-period zone and the peak responses dropped considerably compared with those calculated with the usual method in which ground motion at a single point in a soil is applied directly to a foundation slab.

● 6.8-39 Mizuno, H., **Effects of dynamic inputs on structure-soil-structure interaction**, *Proceedings of the Fifth*

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Japan Earthquake Engineering Symposium-1978, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 68, Nov. 1978, 537–544.

This paper deals with the characteristics of soil-structure interaction for two structures. Emphasis is placed on the effects of dynamic inputs on the interaction system. An analytical model is presented and parametric studies based on the model clarify some basic characteristics of soil-structure interaction. The interaction between an actual building and a model structure is examined on the basis of results of vibration tests, microtremor measurements and earthquake observations performed at a site. The experimental results are compared with the results from the analytical model.

● **6.8-40** Koori, Y., **Analysis of soil-pile-structure interaction system including the effect of adjacent piles** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 67, Nov. 1978, 529–536.

An approximate method is described for analyzing a foundation supported by a group of piles. Pile response is calculated using a superposition technique and the three-dimensional thin-layer finite element method. The seismic-resistant design of pile foundations is discussed. The bearing ratio of the shearing force of piles to that of soil is computed. Included is the effect of a group of piles at various embedment depths.

● **6.8-41** Kobori, T. and Kusakabe, K., **Dynamic cross-interaction between two embedded structures**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 66, Nov. 1978, 521–528.

Vibrational characteristics and earthquake responses of the cross-interaction of two cylindrical structures embedded in a viscoelastic soil stratum are presented. The three-dimensional space model of the soil is assumed to be subdivided by several horizontal planes. A formulation for such a cross-interaction system may be obtained by using a closed-form solution based on the exact displacement functions in the horizontal direction and by using the finite element technique in the vertical direction. Using cylindrical coordinates, an exact solution can be expanded by infinite series for the case of cross-interaction between two foundations with the same circular cross section. In order to analyze the transient coupled responses of the two structures resulting from an impulsive or typical earthquake excitation, the fast Fourier transformation technique is used. The mutual effects of the adjacent structures on their vibrational characteristics and transient responses are discussed in detail.

● **6.8-42** Kitaura, M. and Fukuta, K., **On nonlinearity of velocity dependent damping force of structural foundation and surface layer system** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 65, Nov. 1978, 513–520.

The paper deals with a method for classifying the dynamic-resistant force of a foundation and a surface layer system as a hysteretic restoring force related to response displacement or as a damping force related to response velocity. To investigate the nonlinearity of the damping force curve, model experiments are conducted. A vibrating model having a rectangular section with a hinge at the bottom is used to simplify the phenomena. The model, which can rotate only about the hinge, is excited by an eccentric weight exciter. The frequency response curves and the phase difference curves obtained from experiments are shown. From these curves, it is possible to find the resonant frequencies of the system at every excitation level. The predominant frequency of the surface layer is about 18 Hz. An analysis of the results indicates that the relationship between the velocity and the damping force is nonlinear; i.e., the rate of increase in the damping force decreases as the velocity increases. The degree of nonlinearity is significant when the excitation frequency is lower than the natural frequency of the surface layer and close to the resonant frequency of the system. This tendency can be attributed to the response level and to the energy dissipation caused by waves propagating away from the structure.

● **6.8-43** Kobori, T. and Shinozaki, Y., **Dynamic soil-structure interaction under a topographical site condition**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 62, Nov. 1978, 489–496.

This paper analyzes the two-dimensional dynamic response of a structure with an embedded rigid semi-cylindrical footing welded to a semi-cylindrical alluvial valley. The soil-structure system is subjected to a nonvertically propagating SH-wave. The unknown scattered waves from the rigid footing and the alluvial valley are first represented as infinite series in terms of Hankel and harmonic functions. The scattered waves are transformed into appropriate polar coordinates with the application of Graf's theorem and the Fourier expansion method in order to satisfy the given boundary conditions. Infinite simultaneous equations with respect to unknown coefficients of the scattered waves are obtained. Two physical quantities necessary for evaluating the dynamic response of the soil-structure system, i.e., the impedance function and the driving force of the rigid footing are obtained by solving the simultaneous equations. It is shown that the displacement amplitude of the structure is independent of the incidence angle of SH-waves when the structure is located at the center of the alluvial valley and when sharp peaks

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are shown at the resonant frequencies of the alluvial valley. It also is shown that the more closely the structure is located at the edge of the alluvial valley, the more pronounced become the effects of the incidence angle of SH-waves on the displacement amplitude of the structure.

● 6.8-44 Tsushima, Y. *et al.*, **Study on soil-reactor building interaction: (part 1) experimental study on dynamic ground stiffness in soil-foundation system** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 63, Nov. 1978, 497–504.

The vibrational admittance theory is used to calculate the dynamic soil stiffness in soil-structure interaction problems. Forced vibration tests, seismic observation, and simulation analyses of a foundation model on actual ground are examined. Since the experimental results agree well with the theoretical results, it is concluded that appropriate values of dynamic soil stiffness, including the effects of dissipative damping caused by soil-structure interaction, can be obtained by use of the vibrational admittance theory.

● 6.8-45 Tsushima, Y. *et al.*, **Study on soil-reactor building interaction: (part 2) simulation analyses of forced vibrational test and earthquake observation** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 64, Nov. 1978, 505–512.

Forced vibration test results and earthquake observations of steel frame models are analyzed and compared with results calculated using an analytical method developed by the authors. The analytical method is used to estimate the damping effects of elastic structures. Structures with 1 to 4 stories and reinforced concrete foundations of 7 sq m were modeled. The models had fundamental periods of 0.2 to 0.3 sec, and dimensionless frequencies of 1.0 to 2.0. Good agreement was obtained between the experimental and analytical results. Because of this, it is concluded that the proposed analytical method is useful for the seismic design of nuclear reactor buildings.

● 6.8-46 Muller, F. P. and Ronnberg, K., **Stiff structures on a layered medium under earthquake excitation,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 57, Nov. 1978, 449–456.

A study of the earthquake-induced vibrations of rigid structures on a layered medium is presented. Special emphasis is placed on the influence of dynamic building-foundation interaction. The impedance functions for a layered elastic medium show a much stronger frequency dependence than the impedance functions for an elastic halfspace. The impedance functions for a layered elastic medium are extended to the case of a layered viscoelastic medium making use of the correspondence principle in the frequency range of interest. A linear hysteretic model is assumed for the internal damping in the soil. The equations of motion are first solved for harmonic excitation. It is shown that, for a layered, viscoelastic medium, constant, or frequency-independent, impedance functions can be used as an approximation. For earthquake-induced vibrations, the calculations are performed in the time domain using the method of Foss. Constant impedance functions are determined in an iterative process. An approximated solution is found by the modal analysis method. An equivalent viscous damping ratio is assigned to each mode of vibration. It is determined as a weighted average of the elastic energies stored in the springs of the system. It is found that the modal analysis method gives a good approximation of the exact response for a lightly damped system. For a system with strong damping, however, the use of reduction factors in determining the modal dampings is suggested.

● 6.8-47 Ugai, K. and Yamaguchi, H., **A theoretical study on the seismic behavior of buried pipe** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 55, Nov. 1978, 433–440.

The objective of this study is to analyze theoretically the seismic behavior of buried pipes. Using elastic wave theory, the dynamic coefficients of axial and lateral subgrade reaction for buried pipes of infinite lengths are obtained. These coefficients are the functions of wave velocity, wave length, pipe diameter, elasticity moduli of the ground, etc. It is shown that there are no large differences between the theoretical and the experimental values. Using the results of these investigations, the dynamic response characteristics of pipes with infinite lengths are investigated by means of the vibrational theory. The pipes are modeled as beams on elastic or elastoplastic foundations under both axial sliding and nonaxial sliding conditions. It is concluded that (1) axial and lateral motions of pipes can be represented independently by using the vibrational theory of beams on elastic foundations and by separating the displacement of one incident wave in each component; and (2) under the axial sliding condition, the axial strain of the pipe is at a maximum.

● 6.8-48 Irie, Y., Kitagawa, Y. and Osawa, Y., **Study on soil-building system by means of earthquake observation** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 74, Nov. 1978, 585–592.

The dynamic characteristics of soil-structure systems are examined by comparing the results of earthquake observations for simple soil-structure systems with theoretical results calculated by means of a simple mathematical model. The systems are of three types: a system without a superstructure (SF system); a system with an unbraced-frame superstructure (SFB system); and a system with a braced-frame superstructure (SFBB system). The mathematical model is a simple mass spring system, resting on an elastic halfspace. Since this model does not adequately represent a soil-structure system with layered soil, a modification is made to take into account the effect on the system response of wave reflection at the boundary of the soil layers. The observed frequency and amplitude characteristics are compared with theoretical values.

The results are summarized as follows: (1) The observed frequency characteristics agree satisfactorily with the computed values for all three systems. (2) The maximum displacement obtained by the experiment for the SF system is about twice the computed displacement without consideration of the layered soil effect. (3) The observed maximum magnification factor for the SF model is about 50% larger than the computed factor. However, after consideration of a modification because of the effect of layered soil, good agreement with a difference of 10% is obtained between the observed and theoretical results. In this case, the nonstationary effect of the input wave is small because of large damping in the system. The observed maximum magnification factors for the SFB and SFBB systems are about 40% and 80% of the computed values, respectively. However, after consideration of the effect of the layered soil and the nonstationarity of the input wave, good agreement also is obtained with a difference of 10%. In these cases, the effect of the nonstationarity of the input wave is large, especially for the SFB system, because of the small amount of damping in the system. (4) The ratios of swaying and rocking to absolute displacement, one of the effects of soil-structure interaction, become larger as the building stiffness increases.

● **6.8-49** Suenaga, A. *et al.*, **Observation and analysis of earthquake motion of plant tower built on soft subsoil: simulation of earthquake motion with soil and structure coupled model** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 73, Nov. 1978, 577–584.

This paper examines the modal damping factors, including rocking, of steel tubular petrochemical plant towers. Also examined are the results of linear and nonlinear response analyses. A soil-structure interaction model and observed records of the earthquake motion of the towers built on soft fill are used. The damping factors are obtained by means of the spectrum-fitting technique from the observed and analytical spectra. A lumped-mass interaction model representing two towers, a footing, piles, and the surrounding soil is adopted to simulate the observed earthquake motion. The linear response results show good agreement with observed values, thus, this type of soil-structure coupled model is quite suitable for simulating actual behavior. In the nonlinear response analysis, the soil nonlinearity is expressed by a normalized stress-strain curve. The results show that the acceleration of the response does not increase as yielding occurs in the middle soil layers but that the strain of the piles increases as the near-field soil in the yielded layers deforms.

● **6.8-50** Suenaga, N. *et al.*, **Seismic observation of R.C. high-rise chimney supported by piles on reclaimed ground** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 72, Nov. 1978, 569–576.

The dynamic interaction between a structure and the subsoil is very important for structures built on reclaimed soft subsoil and supported by piles. The authors have been conducting earthquake observations in and around petrochemical plant towers to determine the actual seismic behavior of soils and structures. In addition, a new earthquake observation system has been established in an RC highrise chimney which stands on the soft fill near the petrochemical plant towers. In this report, a summary of the observation system and analytical results based on the observed records are discussed.

The chimney is 150 m in height and supported by many piles which are driven through the soft subsoil into the dense sand at GL-42 m. The composition of the subsoil is roughly separated into five parts, the fill layer from GL to GL-5 m, silty sand from GL-5 to -34 m, clay and sand from GL-34 to -41 m, and sand at the lowest. Three component instruments are placed on the top, middle and base of the chimney. In addition to these, two vertical instruments are placed on the base. These instruments form a triangle for recording the rotational motion of the footing. Seven earthquakes were observed in about a year beginning in June 1977. Their horizontal maximum accelerations are in the range of 4 ~ 24 gal at the chimney base. The amplification ratios of maximum accelerations from the base to the middle and top are 1.0 ~ 2.6 and 5.0 ~ 5.2; these ratios are different in each orthogonal direction. The modal damping factors of the chimney with base rotation were obtained by the spectrum-fitting method. The factors are 0.0 ~ 0.14 for the 1st mode, 0.007 ~ 0.026 for the 2nd mode, 0.021 ~ 0.056 for the 3rd mode, and 0.020 ~ 0.071 for the 4th mode. The conventionally assumed increasing tendency of modal damping factors in the higher mode is not clearly shown.

● **6.8-51** Ohta, T., Niwa, M. and Ueno, K., **Seismic response characteristics of structure with pile foundation on soft subsoil layer** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 71, Nov. 1978, 561–568.

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Earthquake observations have been carried out for a structure with a pile foundation on a soft alluvial subsoil layer. The structure is an 11-story building which is supported by cast-in-place concrete piles driven through the alluvial deposits. The observation system consists of three lines of vertical arrangement that are distant from, nearby, and inside the building. The channels of the accelerometers, the displacement meters, the earth pressure gauges, and the pore water pressure gauges are 27, 8, 4 and 2, respectively.

The seismic response characteristics of the soil-structure system obtained both from observation results and simulation analyses are as follows: (1) The ratio of the maximum acceleration at the basement of the building to that at the ground surface lies between 0.5 and 0.6. (2) The motion of the basement of the building is similar to the free field in the range of the predominant frequency of the subsoil layer. However, in the higher frequency range, the motion of the basement and piles is not similar to that of the subsoil. (3) The damping characteristics of the soil-structure system are approximated to be of the hysteresis type, and the damping values are small for the acceleration levels of the earthquakes considered. (4) An analytical model, which is a combination of the three-dimensional finite element method with a lumped mass system, is used to estimate the soil-structure interaction of the system.

● 6.8-52 Iguchi, M., **Dynamic interaction of soil-structure with elastic rectangular foundation,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 58, Nov. 1978, 457–464.

This paper describes a theoretical analysis of the dynamic interaction of soil and a structure with a rectangular mat foundation. Though the analysis is approximate, a practical method is developed with special consideration of the elastic deformation of the foundation. As an example, the measured results of an actual large shaking table foundation are compared with the theoretical results; and the effects of elastic deformation of the foundation are discussed.

● 6.8-53 Minami, K. and Sakurai, J., **On the earthquake resistant design of soil-foundation-building systems** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 59, Nov. 1978, 465–472.

To calculate the seismic response of soil-foundation-building systems, three seismic wave input procedures can be used. One of these procedures leads to the most accurate results. In this paper, the difference in the response of buildings is investigated for three cases (A, B, and C) calculated using these procedures. For Case C, calculated using the most accurate procedure, the story shear force distributions also are considered. Truss-type models have been used to represent the buildings as two 5 m span widths with an above-ground story height of 3.5 m and a basement story height of 5 m. Buildings with 3, 5, 10, and 15 stories have been analyzed. Predominant periods of vibration are 0.25 sec for hard soil and 0.5 sec for soft soil. The input wave form is the 1940 El Centro motion. The actual seismic wave values are used for Case A; and, for Cases B and C, the maximum acceleration used is 100 gal for the horizontal component and 60 gal for the vertical component applied at the base of the surface soil layers. The response results are analyzed for the base shear and the base overturning moment coefficients. In addition to the El Centro motions, three types of artificial seismic waves are used as input for Case C. The distribution of story shear force in the elastic range is analyzed, and the story shear force distribution equation is presented.

● 6.8-54 Takemiya, H. and Kawano, K., **Layered soil-foundation-structure dynamic interaction** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 60, Nov. 1978, 473–480.

Dynamic interaction between the soil and a structure is of interest for earthquake engineering. This problem has thus far been limited to determination of the surrounding soil impedance functions associated with the substructure motion and the consequent structural response analysis. The use of the substructure method is most advantageous for this purpose. For certain cases, the soil effects are represented by an elastic or viscoelastic homogeneous halfspace. However, in many cases, the soil is layered so that the soft surface deposit lies on more rigid bedrock. The substructure is generally constructed to penetrate through the soft deposit to the supporting rock. In this situation, different wave propagation effects occur. Such a surface layer plays an important role in structural response when the layer is thick.

In this paper, layered soil-foundation-structure interaction is investigated for two structures: an elevated bridge pier with a deep flexible pile and a suspension bridge pier with a rigid caisson foundation. The following conclusions are presented. The vibration modes caused by the reaction of the soil with the structure and those caused by the soil layer are observed. These modes vary with the structural section to be considered. At the substructure, the soil layer effects predominate; at the superstructure, the soil-structure interaction effects increase as anticipated. This indicates that using a spring-dashpot system to model soil-structure interaction may fail to show the correct behavior during earthquake motions unless the effect of the soil layer vibration is incorporated properly. For a rigid foundation, in which the vibration modes between the soil layer and the structural system are clearly not coupled, the proper incorporation can be attained by modifying the input

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motion to reflect the soil layer characteristics. The plane strain impedance function is of use to evaluate the side soil resistance and the halfspace solutions for base reaction. The deterioration of the soil stiffness at the surface portion greatly increases the structural response of a pile foundation. This may be the cause for liquefaction during earthquakes.

● 6.8-55 Migata, K., Tanaka, A. and Imai, H., **Nonlinear seismic response analysis of ground-system and building-ground system** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 61, Nov. 1978, 481–488.

The forced vibration characteristics of a soil system, a soil-slab system, and a soil-structure system, are surveyed. Ramberg-Osgood type soil characteristics are considered. Three sites near Tokyo Bay— Shibamata (hard soil), Minami-Nakadori (soft-to-hard soil), and Ariake (soft soil)—were selected. The soil system had a free surface. For the soil-slab system, a slab weighing 500 t was situated on the soil. In the soil-structure system, the structure was attached at the soil surface. Velocity data recorded at Hachinohe Harbor during the 1968 Tokachi-oki earthquake (E-W component; maximum acceleration 204 gal) were used as input data. A theory of wave propagation for multilayered systems was developed using the characteristics method. Time histories of relative displacement and velocity and the maximum shear force, acceleration, velocity, and displacement in each system were obtained. It was found from an analysis of the displacement response of the soil system that the softer the soil, the greater the displacement. An analysis of the velocity, acceleration, and shear force of the soil system showed that the stiffer the ground, the greater the response. For the soil-slab system, the softer the soil, the smaller the response. The maximum response value of the soil-structure system varied at different heights of the structure depending upon the soil stiffness. The velocity distribution was of an inverted triangular shape for soft-to-hard soil. The distribution of velocity was constant in soft soil.

● 6.8-56 Tsuboi, Y. *et al.*, **A simple analytical method of walled structures considering up-lift of foundation** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 159, Nov. 1978, 1265–1272.

This paper deals with a numerical analysis of the uplift of walled structures on an elastic soil and investigates the effect of this uplift on both static and dynamic properties. Initially, uplift and the contact region are analyzed by the finite element method from the viewpoint of the elastic contact problem. The contact region in the deformed state in this case depends upon the level of loading; thus the geometry of the contact regions is unknown at the start. The numerical analysis described is nonlinear, and requires a complicated calculation technique. To avoid this difficulty, a simple approximate method to determine a relation between the contact region and the seismic coefficient is presented. Five- and eight-storied walled structures on elastic soil are chosen as illustrative examples, and the following characteristics are examined: (1) reaction distribution, stress intensity in the vicinity of the supporting contact region, and stress flow of superstructures resulting from upset; (2) relation between the seismic coefficient and the contact region; (3) load-displacement curves of the soft-spring type; and (4) natural period and response curves.

● 6.8-57 Berardi, R. *et al.*, **Soil-structure interaction analysis of the building "Condominio Giardini" in Maiano,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. II, 567–579. (For a full bibliographic citation, see Abstract No. 1.2-7.)

In this paper, the finite element computer program LUSH is used to investigate the soil-structure interaction problem for a building in Maiano, Italy. Records taken after the Friuli earthquake of May 1976 at the free field, at the basement, and at the top floor of the structure were available. Although the low level of acceleration limits the study, it can be said that there is no interaction effect, except for a certain reduction of the maximum acceleration in the motion recorded at the basement of the building with respect to that measured at the free field. This fact was observed in records obtained from other aftershocks, and it was also found as a result of the analysis performed. Agreement was also found between the normalized acceleration response spectra of the computed and the recorded motion at the basement.

● 6.8-58 O'Rourke, M. and Wang, L. R. L., **Earthquake response of buried pipeline,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 720–731. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Analysis and design procedures for buried pipelines are quite different from the standard procedures developed for structures such as buildings. Seismic design procedures for buried pipelines are based upon two assumptions; one deals with the relative motion between the pipe and the soil and the other with the character of the seismic waves. It is assumed that there is no relative motion between the pipe and the soil and that the shape of the seismic waves does not change as it traverses the pipeline. This paper investigates the assumptions made by the presently available seismic design procedures for buried pipelines subjected to ground shaking.

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● **6.8-59** Wolf, J. P. and von Arx, G. A., **Impedance function of a group of vertical piles,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 1024-1041. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Impedance and transfer functions of a group of vertical piles located in any desired configuration in plan in a horizontally stratified soil layer are derived. Hysteretic and radiation damping are taken into account. The method separates the piles and the soil and introduces unknown interaction forces. The total flexibility matrix of the soil is constructed, superposing the (complex) flexibility coefficients caused by the interaction forces of a single pile only. The dependence of the impedance and transfer functions on the oscillating frequency for foundations with different numbers of piles is investigated. Pile-soil-pile interaction is shown to be very important for all modes of vibration. The procedure is used in the seismic analysis of a reactor building.

● **6.8-60** Novak, M. and Aboul-Ella, F., **Stiffness and damping of piles in layered media,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 704-719. (For a full bibliographic citation, see Abstract No. 1.2-11.)

An approximate theory is presented that makes it possible to include variation of soil properties with depth in the calculation of the dynamic stiffness and damping of piles. This factor is of great significance and its incorporation can considerably improve the agreement between theoretical and experimental results. An extensive parametric study is presented to illuminate the effects of the soil profile, frequency, material damping, free length of the pile, and other factors. Dynamic stiffness and damping of embedded piles are given for the case of parabolic variation of soil stiffness with depth. Charts are presented for use in practical applications. Rigid bodies are also treated.

● **6.8-61** Higgins, C. J., **Ground motion induced interface pressures,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 492-511. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Interface pressures on the sides and bases of embedded cylindrical structures were measured during two experiments in which strong ground shaking was generated with high explosives. The dynamic lateral pressures were found to be related to the horizontal particle velocities while the vertical base pressures were related to the vertical accelerations. These results are explained qualitatively and, in part, quantitatively by a simple wave propagation model in which the structure is modeled as a rigid body and the incoming wave is compressive. This agreement between model and experiment is interesting since the horizontal motion component in the near-surface region contains a substantial shear-wave contribution. It is hypothesized that the shear particle motion, upon interacting with the relatively rigid structure, translates into compression against the structure. As a result, the structure tends to behave in the same way as it would if the incident wave were compressive. If this hypothesis is correct, then pressures induced on embedded structures during earthquakes, thought to contain a significant SH-component, may be related to the motion environment in a way similar to that observed in the explosive experiments, i.e., lateral pressures will be a function of horizontal particle velocities while vertical pressures will be a function of vertical accelerations.

● **6.8-62** Sankaran, K. S., Subrahmanyam, M. S. and Krishnaswamy, N. R., **Dynamics of embedded foundations-a reappraisal,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 413-419.

This paper critically reappraises existing theoretical models for determining the dynamic behavior of footings partially or fully embedded in soil. The models have been reviewed by two approaches. The first approach retains the original concept that the soil can be represented by a linearly elastic, isotropic, and homogeneous halfspace and makes use of the development of lumped system analogs whereby the results of the elastic halfspace theory are expressed in terms of the parameters of a single degree-of-freedom system. The second approach treats the infinite media as a finite model to arrive at numerical solutions. Conclusions are presented and important references are discussed.

● **6.8-63** Sankaran, K. S., Subrahmanyam, M. S., and Sastri, K. R., **Contact shear distribution under machine foundation,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 405-412.

The correct design of a machine foundation requires proper prediction of the resonant frequency, f_n, and the peak amplitude, A_{max}, of a machine foundation-soil system. Research has shown that the elastic halfspace theory is quite satisfactory for predicting the response of machine foundations subjected to vertical vibrations. This paper deals with analytical solutions, numerical evaluations, and corresponding curves for use in analyzing annular ring-uniform contact shear distribution. The purpose is to predict f_n and A_{max} for footings resting on a soil surface and subjected to horizontal vibrations. Field tests have been carried out. The analysis of test data shows that the proposed solutions are quite satisfactory and that they increase the probability of predicting machine foundation response from a single field vibration test.

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● **6.8-64** Clemence, S. P. and Veesaert, C. J., **Dynamic pullout resistance of anchors in sand,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 389–397.

The resistance of buried anchors to dynamic loading was investigated through the use of model anchors tested in laboratory conditions. The soil used for the model was a uniformly graded dry sand placed at a uniform relative density. The test container was 24 in. (61 cm) by 24 in. (61 cm) in cross section and 27 in. (68.5 cm) in depth. Three-inch (5.67 cm) and five-inch (12.7 cm) diameter half-anchors were tested at three embedment depths. The sand was placed in layers of alternating color and the half-anchors were placed adjacent to a transparent side of the test container. A high-speed camera was used during dynamic testing to record the anchor movement and to delineate the failure surface shape for each anchor size and embedment depth. The resulting failure surfaces were compared to those generated by static loading for the same embedment depth and anchor diameter.

The results indicated that the ultimate load resisted by the anchor-soil system under dynamic loading was greater than that for static loading. The resulting failure surfaces for the static and dynamic tests were compared and no discernible difference was found. The failure surface was approximated by a truncated cone with an apex angle equal to the coefficient of friction of the soil. Different types of failure surfaces were noted for shallow and for deep anchor embedments. The difference in failure surfaces was observed to be a function of the depth of embedment to the diameter ratio. A method for predicting the ultimate anchor resistance under dynamic loading is proposed. This theoretical prediction takes into account the inertial forces of the soil mass within the failure zone and the increased shear resistance resulting from dynamic loading. Comparison of the theoretical and measured values of the dynamic pullout resistance for shallow anchors indicates agreement within 15% of the measured values.

● **6.8-65** Chandrasekaran, V. S. and Khedkar, S. P., **Shear wall foundation interaction,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 123–127.

A method of analysis, based on a finite element idealization of a shear wall and on an elastic halfspace model for a soil medium, is presented to account for the influences of interaction between a shear wall and its foundation. The procedure is used in the interactive analysis of a shear wall having a single row of openings and founded on footings. The deflected profile of the wall, the bending moments in the lintel beams, and the horizontal and vertical contact pressures beneath the footings are evaluated. The computations show that both lateral deflections and maximum negative bending moments are underestimated if interaction effects are ignored.

● **6.8-66** Kunar, R. R., Beresford, P. J. and Cundall, P. A., **A tested soil-structure model for surface structures,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 137–143.

This paper describes the formulation of an accurate and efficient finite element model for use in the analysis of surface structures on soil foundations. At the base of the model, viscous elements are introduced to represent the nonreflecting boundary conditions; therefore, the seismic excitation takes the form of a force time history at the base. Since the vertical edges of the model are restrained to move horizontally only, the reflection of radiated waves from this boundary is permitted. Examples are presented to demonstrate that despite this reflection, for nonembedded structures, the model is very accurate. The efficiency of the model is greatly increased because the vertical boundaries need not be very far from the structure and because fewer elements than usual are required to achieve effective frequency transmission.

● **6.8-67** Wedpathak, A. V., Pandit, V. K. and Guha, S. K., **Soil-foundation interaction under sinusoidal and impact type dynamic loads,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 445–452.

The Central Water and Power Research Station, Poona, India, has undertaken during the last decade an extensive prototype vibration survey of massive machine foundations (block-type and frame-type) founded on various types of soil. The purpose is to compare actual experimentally observed vibration intensities with theoretically obtained ones by using various theories of vibration analysis and also to evaluate, in quantitative terms, the influence of soil type on observed foundation vibrations. Although experimentally observed vibration intensities are in general on the order of the theoretically computed values, there are some anomalous observations which can be attributed largely to influences of soil type. The influence of soil type on vibration intensities becomes of paramount importance when foundations rest on soils of a diversified geological nature such as the alluvial soils of the Indogangetic plains, the hard, rocky formations of granite and basalt of peninsular India, and on weathered rock.

● **6.8-68** Arya, A. S. and Kumar, K., **Soil-structure-interaction-effects in structural response to earthquake motions,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 165–172.

The effect of the flexibility of a soil-foundation system on the time period of vibration of some typical structures and their response to earthquake motions is analyzed. The

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soil flexibility is represented by two elastic springs, one translational and the other rotational, to account for the two types of displacements at the foundation of the structure. Results obtained for five structures are presented. Three of the structures have pile foundations, and two have raft-type foundations. One of the structures with a raft foundation is partly submerged in water. The effect on the structural response of the ratio of the structure-to-soil stiffness is investigated for one structure by varying the soil stiffness over a wide range. For structures with pile foundations, the response increases up to a certain soil-flexibility limit and then shows a decreasing trend, whereas for structures on raft foundations, the responses are greater for the fixed-base structures. For the structures with a fundamental period less than 1.0 sec, the second and higher mode responses are insignificant in comparison with the first mode response.

● 6.8-69 Nandakumaran, P., Paul, D. K. and Jadia, N. N., **Foundation type and seismic response of buildings,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 157–164.

The foundation type and the flexibility of a soil-foundation system is an important criterion in the computation of the response of buildings to earthquake ground motion. A simple model with an equivalent lateral spring to represent the stiffness of the soil-foundation system is considered. Also considered is a lumped-mass model of the building. Single-, two-, five-, and ten-story buildings with different foundation flexibilities are analyzed for three types of earthquakes. It is concluded that soil-structure interaction is a very important criterion in determining the response of a structure. There is a possibility that, depending on soil conditions, foundation characteristics alone may be changed to reduce earthquake forces on a structure. The damage data of the 1957 Mexico earthquake have been qualitatively analyzed based on the results of this study.

● 6.8-70 Fang, H. Y. and Koerner, R. M., **Soil-structure interaction during blasting,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 151–156.

This paper presents some factors affecting soil-structure interaction during blasting operations with emphasis on how blasting affects structural response. A new measuring technique which measures in-situ wall cracks during the blasting operation is proposed. Instruments, installation procedures, and measuring techniques are presented. A term, called the cracking intensity factor, is proposed to indicate structural response.

● 6.8-71 Desai, C. S. and Patil, U. K., **Finite element analysis of some soil-structure interaction problems,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 479–495.

This paper provides a review of the applications of the finite element method for soil-structure interaction problems and describes some typical problems solved by the authors by using the FE method. A number of problems in soil-structure interaction can be idealized as two-dimensional plane strain, plane stress, or axisymmetric. As a result, the formulations and solutions are relatively straightforward. However, many other problems require three-dimensional idealization. In this case, the formulation and computer implementation become more involved and expensive. With certain assumptions, it is possible to develop formulations that are intermediate between the two- and three-dimensional idealizations. This approach is semi-analytical and is based on the concept of the separation of variables using Fourier series. The problems presented in this study are based on these three approaches.

● 6.8-72 Iyengar, R. N. and Reddy, A. S., **Response of a soil-pile system during earthquakes,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 355–360.

In this paper, a soil-pile system is modeled using a shear beam for the soil. Constant contact is assumed between the soil and the pile. The problem is solved for free and forced vibrations. The forcing function considered is a seismic displacement applied horizontally at rock level. Numerical results are presented for the free vibration of the soil-pile system and for the surface displacement of the soil-pile system resulting from the seismic displacement at rock level. The results indicate that the model developed may be of value in studying the dynamics of soil-pile systems.

● 6.8-73 Hadjian, A. H., **Foundation-soil interaction—the state-of-confusion,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 181–187.

Two methods of analysis—the impedance method and the finite element method—are used to evaluate the effects of soil-structure interaction. It is expected that the two methods if properly used should provide comparable results. However, this is not the case and in the early 1970s regulatory agencies began dictating the method of analysis for soil-structure interaction. Instead of concentrating upon why the two methods produced contradictory results, a controversy was inadvertently initiated. The present paper reviews the position of the regulatory agencies in light of the research results of the past several years and finds that the position is not representative of the state of knowledge. A solution is suggested whereby the function of the regulatory agencies would be more properly restricted to the establishment of criteria and the method of analysis be left to the practicing engineer. These criteria would point out the considerations that should be included in any analysis. A less desirable solution is a revision of the position of the

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regulatory agencies to reflect recent additions to the understanding of the problem.

● 6.8-74 Bhatia, K. G. and Sinha, K. N., **Effect of soil structure interaction on the behaviour of machine foundation,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 399–404.

A frame foundation for a reciprocating compressor is analyzed. The analysis is carried out by neglecting the effect of soil and by considering the effect of soil. It is observed that the influence of the soil on the response of the foundation is significant. Because of the large amplitude magnitudes caused by the effect of the soil, a cork layer is introduced below the raft.

● 6.8-75 Matlock, H., Foo, S. H. C. and Bryant, L. M., **Simulation of lateral pile behavior under earthquake motion,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 600–619. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The analysis presented in this paper deals with the behavior of a single pile, emphasizing in particular the soil-pile coupling. Simplified superstructure effects are considered, and separately determined free-field soil displacements are used as the input excitation. A discrete-element mechanical analogy is used to represent a pile under various loadings and restraints. The soil-pile coupling at each node is represented by a multi-element assemblage of friction blocks, springs, and dashpots which facilitate the development of hysteretic pile-soil interaction under earthquake loading. The soil model allows strength degradation as a function of deflection and the number of reversals of deflection in the range beyond an initially elastic condition. To properly represent the expected pile-soil interaction, gaps are permitted to form in the upper layers. Lateral earth motions are simulated by moving the supports with respect to the point of initial zero deflection of the pile.

● 6.8-76 Tani, S., ed., **Selected papers of Dr. J. Kazuo Minami** (in English or Japanese), Tokyo Assn. for Science Documents Information, Tokyo, 1978, 201.

This publication compiles papers written from 1937–1978 by J. K. Minami. The topics include soil mechanics and the seismic response of soil-foundation and soil-structure systems.

● 6.8-77 Hwong, S. T., Ghazzaly, O. I. and O'Neill, M. W., **Pile response to dynamic lateral loading,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3309, 1978, 2255–2259.

An approximate method is proposed for the analysis of a pile under low- or high-amplitude dynamic lateral loading applied at the pile head. The soil-pile system is modeled by the vibrations of a beam on an elastic halfspace. The uncoupled spring factor (k) and the damping coefficient (c) of the foundation medium are defined. Appropriate dynamic soil properties are introduced to determine k and c considering both geometric and material damping. The governing equation of motion of the pile is a fourth-order, nonlinear, partial differential equation. Difference equation techniques with an iterative process were used in the solution of this equation for various boundary conditions. A computer program was developed for practical application of the proposed method. The computed results agree fairly well with those measured in instrumented, small-scale pile tests in clay and sand.

● 6.8-78 Matlock, H., Foo, S. H. C. and Cheang, L. C. C., **Example of soil-pile coupling under seismic loading,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. IV, OTC 3310, 1978, 2261–2269.

An example problem is presented to demonstrate a new soil-pile coupling method and to show the behavior of a pile foundation under seismic loading. Computed ground motions based on an existing earthquake record are employed. To properly represent the soil-pile coupling under earthquake motions, a nonlinear, hysteretic and degrading support model, which is also capable of formation of a gap zone near the soil surface, is used in the analysis.

● 6.8-79 Yamahara, H. and Shioya, K., **A study on the filtering effect of foundation slab based on observational records** (in Japanese), *Transactions of the Architectural Institute of Japan,* 270, Aug. 1978, 53–59.

Recent research in the United States has focussed on the filtering effect of rigid foundation slabs in order to develop a rational design method for nuclear power plants. This paper examines the filtering effect of a foundation slab using the earthquake records from the Hachinohe Technical College building during the aftershock of the Tokachi-oki earthquake of 1968 and from the Hollywood storage building during the San Fernando earthquake of 1971. The effective input motions to the building foundation are computed from the free-field motions by passing them through a numerical filter that represents the filtering effect of the foundation slab. The foundation motions thus obtained are compared with the observed records at the building foundation obtained simultaneously with free-field motions. They are found to be very similar to one another. It is well known that the earthquake response of a structure is more or less influenced by the soil-structure interaction effect. However, the filtering effect should be distinguished from the soil-structure interaction effect. To accomplish this, the building is represented by a mathematical model

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including foundation soil, and the transfer function of free-field motion to the foundation response is presented. The transfer function thus theoretically obtained is not similar to that obtained from observed record. It is found that the transfer function in which the filtering effect and soil-structure interaction are taken into consideration is the most similar to that obtained from the observed record. In order to substantiate this effect for use in the design, it is hoped that additional research will be conducted based on different kinds of earthquake observation.

● 6.8-80 Mirza, W. H., **Dynamic behaviour of soil supported foundations,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/23, 1977, 297–303.

This paper discusses the results of experimental and theoretical investigations of foundations resting on soils. The experimental work describes the dynamic behavior of model foundations consisting of blocks and pile foundations and enumerates the parameters which influence the natural frequency and amplitude of motion. The theoretical investigations are based on the mathematical models of soil-supported foundations generated by a computer. The vertical, horizontal, and rocking modes of vibration of the foundations are analyzed and convenient design charts are presented for blocks with various base and plinth shapes.

● 6.8-81 Novak, M., **Soil-pile-foundation interaction,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/25, 1977, 309–315.

Two theories are reported that offer an insight into the dynamic interaction between an elastic pile and soil and also yield the stiffness and damping of the soil-pile system. All vibration modes are analyzed and the results are presented in a readily usable form. A method is proposed for the prediction of the coupled response of pile foundations to horizontal loads in a way suitable for practical calculations. Corrections are suggested to account for those factors not included in the theory.

● 6.8-82 Prakash, S. and Chandrasekaran, V., **Free vibration characteristics of piles,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/29, 1977, 333–336.

Three methods for predicting the free vibration characteristics of soil-pile systems are described. The predicted quantities are compared with results of model and field pile tests. The efficiency of nondimensional solutions based on discrete model idealization is established. The factors influencing the free vibration characteristics are discussed.

● 6.8-83 Rodriguez Ortiz, J. M. and Castanedo, J., **Dynamical behaviour of piles in nonlinear stratified soil,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/33, 1977, 355–358.

A suitable form of the general differential equation governing the dynamic behavior of a pile is used to analyze the nonlinear or hysteretic subgrade reaction of piles in homogeneous or stratified ground on bedrock and subjected to seismic harmonic vibrations. Bending moments, deflections, and natural frequencies are computed. Also investigated are the influence of the end conditions of the pile, the relative percentage of soft or hard layers, and the local plastic yielding of the soil along the height of the pile.

● 6.8-84 Sankaran, K. S., Subrahmanyam, M. S. and Sastri, K. R., **Horizontal vibrations-new lumped parameter model,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/35, 1977, 365–368.

For the proper design of machine foundations, it is necessary to satisfactorily predict the resonant frequency and peak amplitude of the foundation. This paper deals with the development of a new lumped parameter model for the prediction of the response of a machine foundation resting on a soil surface and subjected to horizontal vibrations. The internal damping is represented by an independent parameter and the radiation damping is represented by a viscously damped dashpot. Analytical solutions are presented in graphical form. Field horizontal vibration tests were conducted to check the validity of the analytical solutions. It is found that the model leads to quite satisfactory solutions.

● 6.8-85 Kazame, S., **The damping of a combined system of building-pile foundation-surface layer (in Japanese),** *Transactions of the Architectural Institute of Japan, 266,* Apr. 1978, 11–18.

This paper reports on a study of the damping of a building and considers the effects of the pile foundation and the surface layer upon building vibration. The experiment used models of a single-story building and piles, both made of steel, and a rubber sheet for the surface layer. The models were subjected to free, forced and random vibrations for the following cases: (1) building fixed at the foundation (B), (2) surface layer only ($S.L.$), (3) combined system, i.e., pile foundation (F) and surface layer ($F+S.L.$), and (4) combined system, i.e., building and pile foundation with surface layer ($B+F+S.L.$). Also considered were cases

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(2), (3), and (4) with the surface layer boundary treated as both restrained and free.

From the results of the experiment, the following is shown. In the case of the surface layer with the restrained boundary, the damping of the combined system $(B+F+S.L.)$ is much influenced by the swaying, and it approaches that of $(F+S.L.)$ as the swaying becomes larger. A similar tendency can be seen in the period of vibration. In the case of the surface layer with a free boundary, the vibration mode of the combined system $(B+F+S.L.)$ is dominated by the vibration mode of the surface layer $(S.L.)$ or the pile foundation-building system $(B+F)$. The damping of $(B+F+S.L.)$ approaches that of $(S.L.)$ or of $(B+F)$, which is similar to the tendency seen in the vibration mode of models.

● 6.8-86 Ivanov, P. L. and Sinitsyn, A. P., **Soil liquefaction and stability of foundation,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings,* Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/17, 1977, 265–268.

One- and two-dimensional consolidation problems are considered for saturated noncohesive soils subjected to dynamic, particularly vibration, loads. Taken into account are an occluded gas content and the deformation irreversibility of the vibrocreep process. A method of explosive layer-by-layer sounding is suggested to estimate the possibility of liquefaction, the density, and the dynamic stability of loose saturated soils in situ. Vibrations of a building on a two-layered foundation, caused by seismic elastic and plastic traveling waves, are discussed. In addition, the bifurcation effect that leads to rocking and even to the general loss of stability and overturning of a building is discussed. Criteria for ensuring foundation stability are established.

● 6.8-87 Matsui, G. and Seya, H., **Seismic response of shell structure subjected to spatially variant waves** (in Japanese), *Transactions of the Architectural Institute of Japan, 266,* Apr. 1978, 73–85.

Circumferential higher modes become excited when a large shell structure with a ring foundation is subjected to spatially variant seismic waves. In this paper, it is assumed that the ring foundation cannot be considered rigid since it moves in the same manner as the ground surface. Soil-structure interaction effects are studied for the case of the ring foundation resting directly on the elastic halfspace. The soil-structure interaction effects of the ring foundation are compared with those of a rigid disk in the normal mode. A large hyperbolic cooling tower is analyzed. The height of the cooling tower is 118.5 m, the radius at the base is 57 m, and the entire shell thickness is 30 cm. The width and depth of the ring foundation are 5 m and 3 m, respectively. The columns at the base are not considered.

● 6.8-88 Nath, B. and Soh, C. H., **Seismic response analysis of offshore pipelines in contact with the sea-bed,** *International Journal for Numerical Methods in Engineering,* **13,** *1,* 1978, 181–196.

The seismic behavior of an offshore pipeline which may be totally or partially in contact with the sea-bed is characterized by the confluence of structural dynamics, hydrodynamics, and soil mechanics and also the possible dynamic interactions between these aspects. This paper contains a study dealing with the seismic response analysis of such a pipeline, including pressure drag effects. A numerical analysis is presented based on the assumption that the pipe behaves in a linearly elastic manner and that pipe deflection is elastoplastically related, without loss, to sea-bed resistance. This analysis shows that pipe response is significantly attenuated by contact, the amount of attenuation depending upon contact length and the parameters selected to define idealized sea-bed behavior.

● 6.8-89 Fowler, G. F. and Sinclair, G. B., **The longitudinal harmonic excitation of a circular bar embedded in an elastic half-space,** *International Journal of Solids and Structures,* 14, *12,* 1978, 999–1012.

This investigation concerns the dynamic response of a circular elastic bar of finite length partially embedded in a halfspace with distinct elastic properties. The bar is perpendicular to the free surface of the embedding medium and supports a mass which is harmonically excited in the direction of the bar's longitudinal axis. Two bonding conditions are considered: fully bonded wherein the bar completely adheres to the embedding medium throughout the surface of contact, and loosely bonded wherein the bar is secured through its terminal cross section alone. Of primary importance is the energy dissipation caused by the spatial characteristics of the embedding medium; for this reason, the system is interpreted as a frequency-dependent spring-dashpot. The determination of the effective spring constant and damping coefficient is achieved by modeling the bar by means of a one-dimensional theory and by using three-dimensional theory for a region which approximates the embedding medium, namely, the full halfspace. Lame potentials and Hankel transforms enable a basic halfspace problem to be solved; this in turn allows integral representations for the spring constant and damping coefficient to be established. For the fully bonded problem, these integral representations involve a bar-force term which must be determined from an integral equation. In both cases, the solutions are evaluated numerically over a range of forcing frequencies and for various bar/halfspace configurations.

● 6.8-90 Ponce Cordova, C. A., **Ground effects to structural response,** *Individual Studies by Participants at the*

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International Institute of Seismology and Earthquake Engineering, **14**, Dec. 1978, 277–298.

Soil-structure interaction effects are studied, following a brief discussion of seismic-resistant design principles for structures. Significant soil-structure interaction effects have been observed in numerical analyses, as well as in actual earthquake damage, suggesting the possibility of the adoption of mechanisms to decrease the effects of earthquakes on structures.

● 6.8-91 Grant Perez, R. and Lopez Smith, J., **Aseismic design and analysis of a multi-storied R.C. building,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14**, Dec. 1978, 193–216.

The main purpose of this study is to evaluate the role of a dynamic response analysis in the design of multistory reinforced concrete buildings. A 20-story reinforced concrete building with shear walls on the first floor is analyzed. The building is placed on two types of soil, hard and soft.

6.8-92 Wolf, J. P. and Skrikerud, P. E., **Seismic excitation with large overturning moments: tensile capacity, projecting base mat or lifting-off?,** *Nuclear Engineering and Design,* **50**, *2*, Oct. 1978, 305–321. (Presented as an invited lecture at the Conference on Structural Analysis, Design and Construction in Nuclear Power Plants, Porto Alegre, Brazil, Apr. 18–20, 1978.)

For severe earthquakes, large overturning moments arise which may lead to tension in part of the area of contact of the base mat of the structure and of the soil, according to a calculation based on a linear theory. If no tensile capacity (prestressed anchors, piles) is provided, two different solution procedures are commonly used. The first method consists of enlarging the base mat using projections to avoid tension. In the second, the structure is allowed to lift-off and is designed to resist the nonlinear dynamic response. On the basis of a parametric study, it is concluded that allowing the structure to lift-off generally leads to a reduction of the total accelerations, of the stress resultants, and of the relative displacements within the structure, while the total displacements, the vertical response, and sometimes the response spectra in the higher frequency range are increased, compared to the linear elastic solution with the original base mat. The response using projections is nonuniform when compared to that with lifting-off. It is beneficial to achieve lifting-off to make use of the reduction in the strength requirements. Projection of base mats should be avoided.

● 6.8-93 Aliev, G. A., Korchynsky, I. L. and Borodin, L. A., **On strength reserves and stability of structures against seismic actions,** *HOPE Internationsl JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 117–123.

Based on recent seismological and engineering-seismological data, the consequences are analyzed of a number of destructive earthquakes and earthquakes predicted according to existing methods of calculation. The possible reserves of strength and stability of structures subjected to seismic motion are considered. The results of experimental investigations of these reserves are given.

● 6.8-94 Fardis, M. N. and Cornell, C. A., **Seismic soil-containment interaction: pipe safety,** *Journal of the Engineering Mechanics Division, ASCE,* **104**, *EM6*, Proc. Paper 14218, Dec. 1978, 1353–1370.

The integrity of pipes penetrating the containment wall of a nuclear power plant may be threatened if the containment vessel is subjected to seismic motion. Within the context of an integrated accident and seismic containment reliability study, a methodology is presented to determine the probability of failure of a single pipe and of a system of pipes as a function of the causative ground acceleration. Extreme rocking displacements of the containment under earthquake intensities well beyond the design level are estimated by means of a simple model that takes into account the possibility for soil-base separation and the multidirectionality of the ground motion. The final reliability estimates reflect a large number of uncertainties, most of which are of a statistical nature, i.e., they stem from the limited information about soil properties, details of the seismic motion, and resistance of the pipes. The correlation between failures of apparently redundant pipes introduced by the common dependence on system-wide uncertainties is illustrated.

● 6.8-95 Wang, L. R.-L. and Cheng, K.-M., **Seismic response behavior of buried pipelines,** *Seismic Vulnerability, Behavior and Design of Underground Piping Systems, Technical Report 5,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, June 1978, 11. (Presented at American Society of Mechanical Engineers Annual Winter Convention, San Francisco, Dec. 11-15, 1978.)

Pipeline damage caused by earthquake excitations in the longitudinal direction of a pipeline have been observed to be a major mode of failure. A simplified quasi-static seismic deformation analysis, neglecting the dynamic terms for buried pipelines subjected to earthquake motions in the axial direction, is proposed. The analysis involves the solution of a system of static equilibrium equations of a pipeline which consists of rigid pipe segments and flexible joint springs. By using this model, parametric studies involving soil-pipe interaction parameters, time delay of the traveling seismic waves, soil variations along the

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pipeline, end conditions, and variation of the seismic wave form are performed. Results indicate that the delay time of seismic waves and the nonuniformity of soil resistance have much greater effects on the response behavior of buried pipelines than other parameters.

● **6.8-96** Wang, L. R.-L. and Fung, R. C.-Y., **Seismic design criteria for buried pipelines,** *Seismic Vulnerability, Behavior and Design of Underground Piping Systems, Technical Report 8,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Sept. 1978, 16.

To aid in the design of buried pipelines against earthquakes, this paper evaluates the reserve strength of buried pipes beyond normal stress/strain conditions. This reserve strength is the capacity available in buried pipes to resist seismic loads. In buried pipelines under combined conventional and seismic loadings, biaxial stresses are developed since conventional loads produce mainly hoop stresses and the seismic effect is predominantly in the longitudinal direction. To evaluate the failure of buried pipelines consisting of nonhomogeneous materials (cast iron, concrete, etc.) under a biaxial stress state, a modified Von Mises failure criterion is proposed.

For practical applications, this paper evaluates parametrically the reserve strengths of a typical cast iron (rigid) pipe and a typical ductile iron (flexible) pipe with several important parameters such as aging (corrosion effect), laying and loading conditions, embedment depth, dynamic effect (earthquake-induced water pressure), and trench load uncertainty factor in estimating vertical earth and truck loads. It is concluded that the seismic reserve axial strength of buried pipes is influenced by all the parameters investigated. The effects from corrosion, loading condition, and trench load uncertainty factor are more pronounced than those effects from embedment depth, laying condition, and the earthquake-induced dynamic water pressure effects.

● **6.8-97** Dominguez, J., **Dynamic stiffness of rectangular foundations,** *R78-20,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Aug. 1978, 60.

The boundary element method is applied to the determination of the dynamic stiffnesses of rectangular foundations resting on the surface of or embedded in an elastic halfspace. The procedure is applied to square surface foundations, and the effects of mesh size and relaxed versus nonrelaxed boundary conditions (smooth versus rough footing) are investigated by comparing the results to other published solutions. It is found that the solution for the smooth footing, which is considerably more economical, is practically identical to that of a rough foundation. The static stiffnesses and the frequency-dependent stiffness coefficients are obtained as a function of the aspect ratio for rectangular foundations.

Solutions for embedded foundations are obtained by means of complex coupling between horizontal and vertical forces (and displacements) and a simplified procedure based on relaxed boundary conditions. The approaches show very good agreement; the second approach is computationally much less expensive. The effect of embedment ratio on the static stiffnesses and the dynamic coefficients (frequency dependent) is presented for a square and a rectangular foundation with an aspect ratio of 2.

The boundary element method seems to provide an accurate and computationally feasible procedure for solving three-dimensional soil-structure interaction problems. The method has advantages over finite element solutions, particularly when dealing with a halfspace and embedded foundations.

● **6.8-98** Dumanoglu, A. A., **Error analyses for the application of non-reflecting boundaries to soil-structure interaction problems** (Yansitmayan sinirlarin yapi-zemin dinamik etkilesim problemlerine uygulanilisinda hata analizeri, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **6,** *21,* Apr. 1978, 1-16.

This paper defines the properties of nonreflecting boundaries used for the analysis of soil-structure systems. The use of such boundaries along the base of a system does not require a rigid base assumption. These boundaries are in the form of viscous dashpots and force-time histories developed from only incident wave components of vertically travelling shear waves. A nondimensional analysis was conducted on the size of finite elements used, the shear wave velocity, and the solution frequency in order to define the amount of error involved in each calculation. In the solution distribution, concentrated and average mass matrices were employed. Results show that, when lengths of finite elements in the direction of vertically travelling shear waves are one fifth of the wavelength, then, the amount of error is in the limit of acceptance, if these boundaries are used for interactive problems.

● **6.8-99** Okada, K., Kawamata, J. and Harada, Y., **An experimental study of the effect of embedment-depth having influence upon the horizontal vibration of a single pier,** *Quarterly Reports, Railway Technical Research Institute,* **19,** *4,* 1978, 147-150.

The effects of embedment depth on resonance frequency and maximum displacement were investigated by horizontal vibration tests on a single pier of a frail bridge. The coefficients of static and dynamic soil reaction are compared. Further, the introduction of the coefficient of additional soil reaction is tried. The theoretical and experimental results agree well.

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● 6.8-100 Dominguez, J., **Response of embedded foundations to travelling waves,** *R78-24,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Aug. 1978, 27.

The motion of rigid massless square foundations under various types of seismic waves is studied. Surface foundations are considered and the results, obtained with the boundary element method, compared to those published by other researchers. Embedded foundations under vertically traveling shear waves are studied, and the results compared to those reported by Elsabee and Morray for circular foundations. An embedded foundation under a combination of SV and P waves that will produce a free-field motion compatible with the Newmark-Blume-Kapur spectra is investigated.

6.9 Fluid-Structure Interaction

● 6.9-1 Saini, S. S., Bettess, P. and Zienkiewicz, O. C., **Coupled hydrodynamic response of concrete gravity dams using finite and infinite elements,** *Earthquake Engineering and Structural Dynamics,* 6, *4,* July-Aug. 1978, 363–374.

The finite element method is used to analyze the two-dimensional response of reservoir-dam systems subjected to horizontal ground motion. The interaction between the dam and the reservoir, as well as the compressibility of water, is taken into account. The complete system is composed of two substructures, the reservoir and the dam. Because of its large size, the reservoir is idealized using specially developed infinite elements coupled with standard finite elements. The dam is represented by finite elements alone. Structural damping of the dam and radiation damping in the fluid phase have been accounted for in the analysis. It is concluded that the effect of radiation damping is considerable at high frequencies of excitation. The coupled response of the system is significantly large at and near the fundamental natural frequency of the system in comparison to the uncoupled responses. The method is computationally economical and is capable of taking into account the arbitrary geometry of the system. Further applications and extensions of the approach to three-dimensional analyses are possible.

● 6.9-2 Akkas, N., **Dynamic response of a submerged hemispherical shell to earthquake motions,** *Earthquake Engineering and Structural Dynamics,* 6, *1,* Jan.-Feb. 1978, 89–97.

The dynamic response to ground motion of hemispherical shells in a fluid medium is studied numerically. In the analysis, linear thin-shell theory is used, and the fluid is assumed to be compressible and inviscid. The effect of the ground motion duration on the dynamic response is studied using two forcing functions, one with a very short duration and the other in the form of a Heaviside function. As special cases, dynamic responses of the shell in vacuo and of a rigid hemisphere in the fluid medium are investigated. The results are also valid for a ring-stiffened complete spherical shell accelerating in an acoustic medium.

● 6.9-3 Singh, K. and Mallik, A. K., **Wave propagation and vibration response of a periodically supported pipe conveying fluid,** *Journal of Sound and Vibration,* 54, *1,* Sept. 8, 1977, 55–66.

Propagation of free harmonic waves in a periodically supported infinite pipe has been studied. The presence of the Coriolis term in the equation of motion renders the phase velocity different for the positive- and the negative-going waves; hence, no classical normal modes (in the sense of standing modes) exist. Natural frequencies of a periodically supported finite pipe have been obtained by using the wave approach. The response of the infinite pipe to a convected harmonic pressure field has also been obtained. Because of the difference in the phase velocities of the positive- and the negative-going free waves, the coincidence frequency depends on the direction of the convected loading. The static buckling or the divergence instability of such pipes has also been considered from the wave approach.

● 6.9-4 Dungar, R. and Eldred, P. J. L., **The dynamic response of gravity platforms,** *Earthquake Engineering and Structural Dynamics,* 6, 2, Mar.-Apr. 1978, 123–138.

Gravity platforms and associated regions of foundation and fluid are idealized using the finite element method. Radiation of wave energy away from the platform region is modeled by appropriate damping applied to the boundary of the foundation mesh. Response results are calculated for seven platform-foundation configurations subjected to sinusoidally applied forces. Of particular interest are the results for various assumed foundation conditions, including the presence of stiff soil layers. The response of these platforms to North Sea storm conditions is also estimated. It is concluded that a simple static analysis of the platform-foundation system does not necessarily give an accurate prediction of the response under extreme loading conditions. It is proposed that each prototype platform must be assessed on its individual merits with particular attention given to prevailing geotechnical conditions.

● 6.9-5 Dubois, J. J. and de Rouvray, A. L., **An improved fluid superelement for the coupled solid-fluid-surface wave dynamic interaction problem,** *Earthquake Engineering and Structural Dynamics,* 6, *3,* May-June 1978, 235–245.

The dynamic solid-fluid-surface wave interaction problem can be solved with known finite element solutions. However, these solutions are complicated by the unsymmetric nature of the matrix equation to be solved. This paper shows how the numerical problem can be simplified

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by symmetrization without loss of physical generality by using specialized Lagrangian coordinates for the fluid free surface wave and by introducing a Lagrangian multiplier representing a generalized fluid pressure. With these improvements, solid-fluid-surface wave analysis capabilities can easily be added to most finite element structural analysis programs. Numerical examples of the performance of the improved formulation are given for seismic analysis.

● 6.9-6 Hunt, B. and Priestley, N., **Seismic water waves in a storage tank,** *Bulletin of the Seismological Society of America,* 68, 2, Apr. 1978, 487–499.

The dynamic behavior of inviscid fluid contained in horizontally accelerated cylindrical and rectangular tanks is considered. Mathematical equations describing the fluid motion are developed and simplified by using small-amplitude wave approximations, enabling expressions for free-surface displacements, pressure distributions, and resultant forces and moments on the tank to be obtained. The expressions are formulated in such a way that time-histories of salient parameters can be calculated for tanks subjected to real earthquake accelerograms. Comparisons of predicted and measured free-surface displacements of a model cylindrical water tank subjected to sinusoidal and seismic accelerations on a shaking table indicate close agreement between theory and experiment. Finally, the solutions for seismic accelerations in one horizontal direction are generalized to include acceleration components in all three coordinate directions.

● 6.9-7 Balendra, T. and Nash, W. A., **Earthquake analysis of a cylindrical liquid storage tank with a dome by finite element method,** *UMASS-ENV-76-14833-1,* Dept. of Civil Engineering, Univ. of Massachusetts, Amherst, May 1978, 175.

An elastic cylindrical liquid storage tank with an elastic dome is considered. The tank is attached to a rigid base slab. The liquid in the tank is assumed to be inviscid and incompressible. A finite element analysis is presented for the free vibrations of the coupled liquid-elastic system permitting the determination of natural frequencies and associated mode shapes. The response of a partially or completely filled tank to an artificial earthquake excitation is also determined through use of finite elements. Examples, together with program listings, are offered. The computer programs are valid for any axisymmetric dome attached to the top of a cylindrical tank. Both the cylindrical tank and the dome may have variable thicknesses and variable rigidity.

● 6.9-8 Wieland, M., **Earthquake resistance of a gravity dam-reservoir-foundation system,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-56, 1978, 421–428.

This study concerns an idealized two-dimensional gravity dam-reservoir-foundation system. The scaled seismograms of the Pacoima Station, recorded during the 1971 San Fernando Earthquake, are used as input. The infinite extent of the underground and also partly of the reservoir is simulated by using Lysmer-Kuhlemeyer energy-absorbing boundaries. Linear elastic behavior of the mass concrete and of the rock foundation is assumed, while the water in the reservoir is considered to be a compressible liquid.

● 6.9-9 Bickovski, V., **Soil-dam-fluid interaction,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-57, 1978, 429–437.

The dynamic response of a soil-dam-fluid system has been studied, and an analytical solution for the determination of the dynamic properties of an arch dam is presented. Two separate cases are considered: the first involves the influence of the interaction of the soil media and the fluid on the dynamic response of the dam; the second involves only the soil and the dam. It is concluded that the soil-fluid interaction has an important influence on the dynamic response of the dam.

● 6.9-10 Parkus, H. and Grossmayer, R., **Sloshing frequency of a liquid in a flexible cylindrical tank,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-64, 1978, 479–483.

An approximate analytical solution is presented for determining the eigenfrequencies of a liquid sloshing horizontally in a cylindrical tank. Flexibility of the tank is taken into account. Numerical results show the expected reduction of the eigenfrequencies caused by the flexibility of the tank.

● 6.9-11 Barbat, H., Breaban, V. and Barbat, E., **Seismic analysis of elevated water tanks—a new interaction model,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-62, 1978, 465–470.

This paper establishes a dynamic model for computing the seismic response of elevated water tanks. The model provides good agreement with the actual behavior of this type structure. The model considers fluid-structure and soil-foundation interaction but avoids a complete substructure analysis which involves extensive computation.

● 6.9-12 Vulpe, A., Poterasu, V. F. and Mihalcea, A., **General system concept of interaction problem in seismic analysis for reservoir system-flat upstream dam,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-60, 1978, 451–458.

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An analytical method is presented for determining the seismic response of a flat upstream dam by interconnecting the subsystems (reservoir, dam, and foundation). A mathematical model based on calculus is proposed. The analysis of the hydrodynamic pressures includes the effects of the general flexibility of the dam cross section and the influence of the vertical earthquake component. The dam-foundation interaction of the extension of the afferent foundation domain is considered.

● **6.9-13** Clough, R. W., Clough, D. P. and Niwa, A., **Seismic response of cylindrical tanks,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-14, 1978, 111-118.

Shaking table tests of two one-third scale tanks, 12 x 6 ft and 7-3/4 x 15 ft, are described and the observed dynamic response is compared with predictions made by standard seismic design procedures, considering both fixed and free base conditions. An important observation is that significant out-of-round displacements are induced, apparently due to initial imperfections of the tank. These lead to erratic correlations between observed and predicted tank stresses.

6.9-14 Tani, J. and Doki, H., **Vibration and buckling of fluid-filled cylindrical shells under torsion,** *Nuclear Engineering and Design,* 48, *2&3,* Aug. 1978, 359-365.

On the basis of the Donnell-type equations modified with the transverse inertia force, the free vibration and the buckling of fluid-filled circular cylindrical shells under torsion are analyzed theoretically by using Galerkin's method. The fluid is assumed to be incompressible, irrotational, and inviscid. Calculations are carried out for a typical simply supported shell. It is found that the natural frequency of the shell under torsion decreases rapidly with the internal fluid but that the buckling load of the fluid-filled shell agrees precisely with the buckling load of the empty one.

● **6.9-15** Warburton, G. B. and Hutton, S. G., **Dynamic interaction for idealized off-shore structures,** *Earthquake Engineering and Structural Dynamics,* 6, 6, Nov.-Dec. 1978, 557-567.

This paper examines a structure idealized as a uniform slender beam of circular cross section which supports a rigid tip mass and which is connected at its base to a rigid foundation mass, the latter being attached to the surface of a viscoelastic halfspace. An analytical solution for the harmonic response of the partially submerged structure is obtained in terms of the normal modes of the corresponding structure *in vacuo.* This is achieved by introducing fluid-structure coupling into the model. A similar structural model has been described in a companion paper and has been used to study soil-structure interaction. Numerical results show the dependence of the response on various parameters, and contribute to a better understanding of the dynamics of offshore towers.

● **6.9-16** Dong, R. G., **Effective mass and damping of submerged structures,** *UCRL-52342,* Lawrence Livermore Lab., Univ. of California, Livermore, Apr. 1, 1978, 73.

Various structures important for nuclear power plant safety must continue to function in the event of an earthquake or other dynamic phenomena. Because some of these structures, such as spent-fuel storage racks, main pressure-relief valve lines, and internal structures in the reactor vessel are submerged in water, dynamic analysis must include the force and damping effects of water. This report provides a technical basis for evaluating the wide variety of modeling assumptions currently used in design analysis. Current design analysis techniques and information in the literature, obtained by surveying 32 industrial firms and reviewing 49 technical references, form the basis for the conclusions and recommendations. The findings generally pertain to idealized structures, such as single isolated members, arrays of members, and coaxial cylinders, but are related to actual reactor structures through observations and recommendations. When possible, a way to evaluate the effect of hydrodynamic forces on these structures is recommended.

● **6.9-17** Watt, B. J., Boaz, I. B. and Dowrick, D. J., **Response of concrete gravity platforms to earthquake excitations,** *Journal of Petroleum Technology,* Mar. 1978, 318-324. (Presented at the Eighth Annual Offshore Technology Conference, Houston, May 3-6, 1976.)

The earthquake response of typical concrete gravity structures in 100 to 200 m of water is evaluated. Response spectrum and fast Fourier transform solution techniques are used. Parametric studies show that the analysis method markedly affects magnitude and distribution of computed foundation and structural forces and that correct modeling is essential.

● **6.9-18** Karadeniz, D. H., **Dynamic analysis of rotational thin shell-fluid systems** (Donel ince kabuk-sivi sistemlerinin dinamik hesabi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 5, *19,* Oct. 1977, 17-44.

In this paper, the dynamic behavior of axisymmetrical thin-shell structures either surrounded by water or containing fluid is studied. The finite element method is used in the analysis. A quadrilateral subparametric fluid element with changeable meridional curves (which differs from the conventional elements) as functions of parametric variables controlled by data input is presented. The inertia vector of fluid elements resulting from earthquake excitation and the

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coupled problem of the structure-fluid system are formulated. The algorithm of a technique which uses minimum computer storage is presented for the solution of the coupled eigenvalue problem. The accuracy of solutions is demonstrated by numerical examples.

●6.9-19 Hamamoto, T., Konishi, N. and Tanaka, Y., **Study on dynamic behaviors of shell-type offshore towers during earthquakes**, *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 131, Nov. 1978, 1041-1048.

The dynamic response of fixed offshore towers subjected to earthquake ground motion is studied. The mathematical model of the offshore tower structure used in this investigation is a cantilever circular cylindrical shell; and therefore, an important aspect of the problem is the exterior fluid-shell interaction. In the analysis, the following assumptions are made: (a) the shell is thin and elastic, (b) the water is inviscid, incompressible, and irrotational, (c) the effects of surface waves can be ignored, (d) the amplitude of motion is small and, therefore, a linear analysis is sufficient. The hydrodynamic pressure generated by the vibrating structure is obtained by potential flow theory. The response to ground motion is determined by step-by-step integration of the modal equations of motion, which are derived by the energy method. Three offshore towers having different values of height-to-radius ratio are considered in order to perform example analyses. The numerical computations for each tower are carried out.

●6.9-20 Ishii, H. *et al.*, **Vibrational characteristics of large-sized cylindrical flat bottom storage vessel** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 150, Nov. 1978, 1193-1200.

Shaking table tests were conducted on a cylindrical flat-bottom storage vessel made of prestressed concrete (PSC) and a double-walled storage vessel, the outer shell of which was made of PSC (PSC/metal double-walled tank). The purpose was to examine the earthquake resistance and the design safety factors of the vessels. In addition, to verify the dynamic properties determined from the tests, analyses were carried out by means of simple numerical models. The design of the vessels was similar to the design of cryogenic storage tanks. The large shaking table of the National Research Center for Disaster Prevention was used for the tests.

For the PSC vessel, the nonlinear response caused by even-order higher harmonics was dominant, amplifying the deformation in the θ direction. The resulting stress even from the shaking which exceeded the design seismic coefficient fell within the elastic range and the slightest fluctuation of the prestress introduced to the shell was demonstrated; thus, the results showed satisfactory earthquake resistance. For the metal vessel, the linear response caused by the primary natural frequency was dominant; and the local stress concentration at the anchor straps, lower shell plates, etc., which had been a controversial problem, was verified. For the PSC/metal double-walled tank, the inertial force of the liquid exerted on the outer PSC vessel was damped by the plastic action of the granular insulating material. These properties of the double-walled tank were similar to the properties of the single-walled PSC vessel. The dynamic hydraulic pressure exerted a substantial effect on the upper wall in the form of sloshing waves and on the fixed roof in the form of impulsive water columns. As for the sloshing waves, the results obtained correspond to those obtained by Sogabe.

As a result of these numerical analyses, it was found that the axisymmetric eigenvalue analysis by the finite element method which converted the liquid into the concentrated masses on each nodal point proved to be effective in obtaining the eigenvalue of the vessel. The axisymmetric stress analysis by the finite element method which evaluated the dynamic hydraulic pressure as a static load provided almost satisfactory results, except for the numerical correlation between the load and the nonlinear response in the θ direction which was still to be examined. Using the results, the vessels demonstrated sufficient seismic resistance to a maximum estimated magnitude earthquake.

●6.9-21 Tani, S., Tanaka, Y. and Hori, N., **Seismic analysis of thin cylindrical tanks containing liquid** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 151, Nov. 1978, 1201-1208.

This report presents the elastic effects of cantilevered circular cylindrical shells partially filled with liquid and subjected to horizontal excitations by means of the Rayleigh-Ritz method. Thin cylindrical shells are considered for the containers, and the internal liquid is assumed to be an ideal liquid. The fundamental equations are obtained based on the linear theory with small deflections and the linear potential flow theory. The displacements of the shells in the axial coordinates are approximated by a series of functions for the flexural vibration modes of a cantilevered beam. Donnell's equations of displacement-strain relationships are adopted and the accuracy of Donnell's equations are shown by comparisons with the numerical results from Flugge's equations. The pressure of the internal liquid is separated into convective and impulsive pressures. Since the frequencies of the first few dominant modes of liquid sloshing are usually much smaller than the frequencies of the liquid-shell system, the effects of elastic deformations of the shells on the convective pressure are neglected; and, for the impulsive pressure, the free surface of the liquid is assumed to be rigid. The velocity potential for the impulsive pressure which satisfies the boundary conditions on the wet surface is represented as a sum of the particular and homogeneous solutions. The impulsive pressure then is represented as the sum of pressures induced by the rigid motion and elastic deformation of the shell. Generalized forces given by these pressures are substituted into Lagrange equations, and the response pressures are solved by modal analysis. Numerical computations prove that the response pressures when considering elastic deformations of the shells are larger than the pressures when considering only rigid motions of the shells. From the response pressures, the stress results of the shells are calculated by means of the finite element method. These are compared with the stress results calculated by means of the base shear coefficient from static forces applied to the shells. The results show that the static force overestimates the stress.

● **6.9-22** Ujihashi, S., Matsumoto, H. and Nakahara, I., **Dynamic responses of a circular cylindrical storage tank subjected to translational motions of its foundation** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 152, Nov. 1978, 1209-1216.

This paper deals with the transient analysis of the dynamic displacements and stresses in a circular cylindrical storage tank subjected to earthquake loads. The upright storage tank is partially filled with a liquid. The lower edge is fixed to a rigid foundation, and the upper edge is free. For simplicity, the liquid is replaced by a fixed-mass, the weight of which is identical to the total weight of the liquid. Earthquake loads are simulated by horizontal harmonic motions of the foundation defined mathematically as the loading function. Exact solutions for the tank are given on the basis of Flugge's shell theory and by use of the Laplace transformation. The maximum dynamic values for the displacements and stresses in the tank are shown graphically. The effects of the period of the loading function, the depth or the density of the liquid, and the wall thickness or the height of the tank are mentioned. The amplitude of the displacement at the upper edge of the empty tank extends when the period of the loading function is shorter than twice that of the lowest fundamental natural frequency of the tank. This critical period of the loading function becomes long when the volume or the density of the liquid is increased. The same effect occurs when the thickness of the tank wall is increased. The amplitudes of the stresses at the lower edge have the same inclination as the amplitudes of the displacement. In comparison of the frequencies given by this analysis and those given by the experiment using water as the liquid, it is found that the approximation of the liquid to the fixed-mass yields an overestimation of the mass of the liquid.

● **6.9-23** Kondo, H., **Vertical free vibration analysis of an elastic circular cylindrical tank with a liquid,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 77-83.

The coupled oscillations of a liquid and a circular cylindrical storage tank when subjected to small motions are studied. The liquid is assumed to be a perfect fluid, the side wall of the tank is treated as an elastic circular cylindrical shell, and the tank bottom is assumed to be rigid. The method of separation of variables is used to obtain series form solutions for the axisymmetric case. Velocity potential is introduced to depict the liquid motions and is expressed by the series expansion of an orthogonal system. The side wall is treated as being freely supported at both ends, thus enabling its motions to be expressed by a trigonometric series. Frequency equations are obtained and numerically solved to illustrate the effect of coupling. The results show that in lower eigenfrequencies, motions are mainly a result of liquid surface sloshing and that in higher eigenfrequencies, so-called bulging modes emerge which consist mainly of the sinusoidal motions of the side wall.

● **6.9-24** Finn, W. D. L. and Varoglu, E., **Dynamic interaction of a dam reservoir foundation system,** *International Symposium on Soil-Structure Interaction,* Sarita Prakashan, Meerut, India, Vol. I [1977], 467-478.

A method of analysis is presented for the seismic response of a dam-reservoir-foundation system. The hydrodynamic pressures generated in the reservoir have been evaluated in closed form as a function of the displacements of the dam-reservoir interface. These displacements are expressed in terms of the deformations of the dam and the translation and rotation of the base. The motions of the dam resulting from translational and rotational harmonic motions of its base are determined by finite element techniques. The frequency-dependent amplitudes of the translation and rotation of the base are found by solving the coupled equations of motion of the dam-reservoir and the halfspace. The general flexibility of the dam cross section, the compressibility of the water and the radiation damping in the infinitely long reservoir, and the halfspace foundation are taken into account in the analysis. The viscosity of water and the effect of surface waves are neglected.

● **6.9-25** Sasaki, Y. and Yoshizawa, H., **Pipe rupture by seismic vibration and static repeated bending test,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 165-172.

The seismic response of pipes used in atomic power plants was tested. The model pipes, carbon steel nuclear pipes, were placed on a slippery table and pressurized internally with water. They then were subjected to dynamic stress. They were oscillated for a few hundred cycles corresponding to the vibration of a large earthquake and a vibration force large enough to burst the pipes. It becomes clear that, when a big earthquake occurs, pipes under internal pressure, such as pipes in atomic power plants,

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would swell as a result of the ratchet phenomenon and rupture at the tapered part because of intense plastic strain concentration.

● 6.9-26 Byrd, R. C. and Nilrat, F., **Earthquake excitation of submerged tanks and caissons: a correlation study for physical and analytic models**, *Offshore Technology Conference—1978, Proceedings of Tenth Annual*, Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3110, 1978, 503-511.

A study has been conducted to compare the results of measurements of forces on submerged tanks and caissons caused by earthquakes with analytical techniques used to determine such forces. Experimental results are presented from harmonic tests conducted on a 1 to 100 scale model representing a cylindrical structure 34 m in height and 80 m in diameter with a mass of approximately 250,000 t. Inertia force coefficients calculated from these tests are compared with coefficients derived by linear diffraction theory for the totally submerged case and by a closed-form solution for the surface-piercing case. The proper use of added mass coefficients to represent fluid-structure interaction in the equation of motion is discussed.

● 6.9-27 Vandiver, J. K. and Mitome, S., **The effect of liquid storage tanks on the dynamic response of offshore platforms**, *Offshore Technology Conference—1978, Proceedings of Tenth Annual*, Offshore Technology Conference, Dallas, Texas, Vol. II, OTC 3162, 1978, 993-1000.

The sloshing of liquids in storage tanks on fixed offshore structures affects both the natural frequencies and damping of the structures. Analytic procedures to account for these effects are presented. Also shown is a method for the design of tanks that will result in suppression of dynamic response at the fundamental flexural natural frequencies of the structure. One advantage of this method is that no new equipment is required. Optimum configuration of tankage already required for storage of water, fuel, mud, or crude oil is needed.

● 6.9-28 Dungar, R., **An efficient method of fluid-structure coupling in the dynamic analysis of structures**, *International Journal for Numerical Methods in Engineering*, 13, *1*, 1978, 93-107.

A method of fluid-structure connection is presented for solutions which mainly involve the calculation of the dynamic response of structures by modal analysis. This connection method is based upon finite element structural and fluid representation and is efficiently employed when used with the inverse iteration procedure for eigenvalue—eigenvector evaluation. The inverse iteration procedure is described in conjunction with the connection method. Also, a method of nonlinear structural analysis and a method of frequency domain analysis are discussed with reference to the fluid-structure connection procedure. Applications are considered for both model and prototype situations. Efficient use of the mini-computer for solving dynamic problems by the proposed method is also considered.

● 6.9-29 Zienkiewicz, O. C. and Bettess, P., **Fluid-structure dynamic interaction and wave forces. An introduction to numerical treatment**, *International Journal for Numerical Methods in Engineering*, 13, *1*, 1978, 1-16.

This paper presents an introduction to two general approaches used in the solution of coupled structures and fluid systems in which the effects of large-scale flow are excluded. The first is the Lagrangian approach in which the fluid is simply treated as a solid with a negligible shear modulus. The second is the Eulerian method, in which a single-pressure variable is used in the fluid. The numerical problems posed, the discretization methods used, and possible simplifications are discussed.

● 6.9-30 Byrd, R. C., **A laboratory study of the fluid-structure interaction of submerged tanks and caissons in earthquakes**, *UCB/EERC-78/08*, Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1978, 167. (NTIS Accession No. PB 284 957)

An experimental study comparing the results of measurements of forces on a submerged tank model resulting from earthquake excitation is presented. The experimental results are compared with analytical solutions for the case where the model is submerged in water of a depth equal to 2.5 times the tank height and for the case where the depth exactly equals the height. Details are presented for the design of a 1- to 100-scale model of a circular cylindrical structure which is 34 m in height with a mass of approximately 250,000 tons. The model includes a foundation system which simulates elastic halfspace soil stiffness in three degrees-of-freedom.

The experimental results are presented in the form of inertia coefficients measured in harmonic motion at varying amplitudes and over a frequency range of 0.3 Hz to 2 Hz in prototype-scale. Coefficients are presented for horizontal, vertical, rotational, and horizontal-rotational coupling. The relationship between these coefficients and the physics of the fluid-structure interaction are discussed in detail.

The study leads to the following conclusions concerning earthquake-induced forces on large submerged, gravity-type structures: (1) Available analytical techniques provide good estimates of hydrodynamic inertia force coefficients for submerged structures of simple form. (2) A correct estimate of foundation dampening is likely to be the most critical point in calculating the hydrodynamic forces on a submerged gravity structure. (3) Foundation stiffness only influences the hydrodynamic force by changing the resonant

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frequency. (4) Frequency dependence in the inertia coefficients is not likely to be an important consideration. (5) Coupling in the hydrodynamic inertia forces between the horizontal and rotational modes is not likely to be an important consideration in structural design. (6) Hydrodynamic dampening will not be an important factor for deeply submerged structures but may be significant in near-surface and surface-piercing structures.

● 6.9-31 Nelson, I., **Axial vibrations of a fluid filled pipe,** *Technical Note No. 1,* Weidlinger Assoc., New York, Nov. 1978, 9.

Many pipelines cross seismically active regions where they may be subjected to damage from earthquake-induced ground shaking. The pipe motion may be in the lateral or axial directions, or both. Novak and Hindy show that axial stresses may be an order of magnitude or more than bending stresses. Thus, axial motion should be given first attention. In an earlier paper, Nelson and Weidlinger modeled a pipeline as a discrete system of rigid links connected to each other and to the ground by springs and dashpots. The model is a natural one for a pipe consisting of stiff segments connected by relatively soft joints. They showed that the peak relative motion across a joint may be estimated using spectral techniques, where the frequency and damping ratio may be expressed in terms of the assumed mass, spring and dashpots coefficients of the system.

Leaving aside the much more difficult problem of estimating the soil-pipe interaction coefficients, the question remains as to the effect of the enclosed fluid on the mass and damping coefficients. Many authors have studied solid-fluid interaction phenomena when the relative motion is normal to the walls of the solid. When the relative motion is parallel to the walls of the pipe, i.e., axial motion, some authors have assumed that a certain fraction of the mass of the fluid participates in the pipe response. However, little analytical or experimental work is available to estimate these effects on a more rational basis. This paper discusses the question of fluid-pipe interaction when the only mechanism for coupling is the fluid viscosity.

6.10 Vibration Measurements on Full Scale Structures

● 6.10-1 Foutch, D. A., **The vibrational characteristics of a twelve-storey steel frame building,** *Earthquake Engineering and Structural Dynamics,* **6,** *3,* May-June 1978, 265–294.

The Ralph M. Parsons World Headquarters building, a twelve-story steel frame structure, was subjected to a series of forced vibration tests. The natural frequencies, three-dimensional mode shapes, and damping coefficients of nine modes of vibration were determined. Other features of this investigation included the study of nonlinearities associated with increasing levels of response, detailed measurements of the deformation of the first floor and the ground surrounding the structure, and measurements of strain in one of the columns of the structure during forced excitation.

The dynamic characteristics of the building determined by these tests are compared to those predicted by a finite element model of the structure. The properties of primarily translational modes are predicted reasonably well, but adequate prediction of torsional motions is not obtained. The comparison between measured and predicted strains suggests that estimates of stress determined from finite element analyses of buildings might be within 25% of those experienced by the structure for a known excitation.

6.10-2 Kulkarni, G. G. and Ng, S. F., **Dynamic analysis of two dimensional simply supported orthotropic bridge decks,** *Canadian Journal of Civil Engineering,* **5,** *1,* Mar. 1978, 58–69.

Forced vibration analysis of two-dimensional bridge deck structures involves complex mathematical procedures; therefore, analysis is often based on beam idealization of equivalent plates. This simplification yields close agreement only for long-span bridges where plate action is relatively insignificant. However, such a concept of beam idealization cannot be successfully utilized for short-span bridges where plate action is predominant and where the determination of the distribution of dynamic deflections and amplification factors at critical sections of such plates is of prime concern. The principal objective of this investigation is the forced vibration analysis of longitudinally stiffened, simply supported orthotropic bridge decks utilizing a new concept of interconnected beam idealization. The theoretical analysis deals with determination of amplification factors and dynamic deflections along critical sections of the plate treated as a series of interconnected beams. The aspect ratios of the plates under investigation as series of interconnected beams are designed to cover a wide range of plate-to-beam transition. The theoretical analysis is supplemented by an extensive experimental program.

This concept of interconnected beam idealization not only takes into account the plate action of the deck structure but also greatly reduces the complexity of mathematical formulation. A good comparison between the theoretical and the experimental results indicates that this concept can be used to advantage for analysis and, within certain limitations, for design.

● 6.10-3 Foutch, D. A. and Jennings, P. C., **A study of the apparent change in the foundation response of a nine-story reinforced concrete building,** *Bulletin of the Seismological Society of America,* **68,** *1,* Feb. 1978, 219–229.

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Forced vibration tests of the Millikan Library building, a nine-story reinforced concrete shear-wall structure, were conducted in 1966 and 1967, before the San Fernando earthquake, and again in 1974. The measured foundation response of the structure reported for the tests was significantly different: in the earlier tests, motion of the foundation in the N-S direction contributed only about 3% to the total roof motion, whereas in the more recent tests almost 30% of the roof motion was contributed by foundation compliance. A lengthening of the fundamental period of vibration of 11% was also noted.

This study examines the indication that the foundation response of the structure may have changed because of the earthquake. To determine whether the observed changes in foundation response are consistent with the change in natural period, two analytical models of the Millikan Library building were developed. Both of these models include the effects of foundation compliance, and one includes the effects of shear deformations in the walls of the structure. The results show the changes of mode shape and period between the tests to be consistent. From the analysis and from an examination of what is thought to be minor earthquake damage at the ground floor level of the structure, the authors conclude that the most probable cause of the differences observed in the two tests is the loss of rotational and translational stiffness provided by retaining walls, concrete slabs, and other stiff, but brittle, elements.

● **6.10-4** Paskalov, T. and Taskov, L., **Damping determination from full-scale experiments,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-21, 1978, 151-158.

The influence of factors which affect the evaluation of the damping characteristics of large-panel prefabricated and shear wall reinforced concrete structures is discussed. The procedures for full-scale forced vibration studies of such structures are also presented. The damping characteristics of the normal modes of vibration are obtained as a function of the input excitation or as a function of the interstory displacements resulting from the forced vibration excitation. The procedure enables the selection of structural damping values to be carried out in a rational and systematic manner.

● **6.10-5** Galambos, T. V. and Mayes, R. L., **Large-scale dynamic shaking of 11-story reinforced concrete structure,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-01, 1978, 1-9.

The test building was an 11-story framed reinforced concrete tower structure approximately 40 ft square. The periphery and stairwell were enclosed by block and/or brick walls which were interrupted intermittently by windows. The building was designed in 1953 under the then-effective ACI Code. No special provisions were made to resist seismic loads. In the E-W direction with infill panels in place, the building was subjected to approximately 1.2 times the 1974 SEAOC equivalent base shear for Zone 4 with $K = 1.0$ and $S = 1.5$. The resulting amplitude of the top floor motion was ± 6 in. In the N-S direction with the infill panels removed, the building was subjected to approximately 3 times the 1974 SEAOC equivalent base shear for Zone 4 with $K = 1.0$ and $S = 1.5$. The resulting amplitude was ± 18 in. These and other results are presented in the paper.

● **6.10-6** Jurukovski, D., Petrovski, J. and Taskov, Lj., **A cantilever beam model of a 22 storey building with included translation and rotation of the foundation,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-05, 1978, 37-43.

A forced vibration test was carried out on a 22-story building constructed as a large panel system on pile foundations. The experimental results point to the considerable soil-structure interaction effect. For illustration of the soil-structure interaction effect, a simple analytical model was designed which gives a good correlation with the experimental results. Rotary inertia and shear distortion were included in this model.

● **6.10-7** Petrovski, J., Jurukovski, D. and Simovski, V., **Dynamic response of building with isolation on rubber cushions,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-04, 1978, 29-36.

Dynamic response of a three-story reinforced concrete school building with foundation isolation constructed in Skopje is represented and discussed. Foundation isolation was achieved by applying rubber cushions between the strip foundation and the ground floor slab of the superstructure. Full-scale studies were carried out to determine the dynamic properties of the building. The response of the building is analyzed.

● **6.10-8** Petrovski, J., Talaganov, K. and Galbov, S., **Experimental dynamic response study of a turbo-generator foundation and mathematical model formulation,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-08, 1978, 61-66.

The results of a full-scale forced vibration study of a 200 MW turbogenerator pedestal are compared with the results of a dynamic response analysis. The effect of soil-foundation interaction is studied and its predominant influence on the dynamic response of the turbogenerator

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pedestal found. Mathematical modeling of the system using approximate solutions is performed, and analytical response data are compared with the experimental results.

● 6.10-9 Bouwkamp, J. G., **Dynamic studies of a 16-story office building with cable-suspended floors,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-02, 1978, 11-18.

The paper describes the results of a two-phase experimental forced-vibration study of a building with a central reinforced concrete core and suspended floors. The tests first were carried out on the core before the floors had been installed. After the steel floor beams had been hung from bridge-strand cables and the concrete slabs had been poured, the completed building again was tested dynamically. The experimental results, as natural frequencies and mode shapes, were found in excellent agreement with computed values derived from two simplified mathematical models.

● 6.10-10 Abdel-Ghaffar, A. M. and Housner, G. W., **Ambient vibration tests of suspension bridge,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM5,* Proc. Paper 14065, Oct. 1978, 983-999.

Extensive experimental investigations were conducted on the Vincent-Thomas Suspension Bridge at Los Angeles Harbor to determine natural frequencies and mode shapes of vertical, torsional, and lateral vibrations of the structure. These ambient vibration tests involved the simultaneous measurements of both vertical and lateral vibrational motions caused by traffic. Measurements were made at selected points and different cross sections of the stiffening structure. Comparison with previously computed mode shapes and frequencies showed good agreement with the experimental results, thus confirming both the accuracy of the experimental determination and the reliability of the method of computation.

● 6.10-11 Sotirov, P., Tzenov, L. and Boncheva, H., **Analysis of a damaged tower type structure during Vrancea earthquake,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-30, 1978, 239-243.

Vibration tests were performed on a seventeen-story reinforced concrete slip-form building in Sofia after the Vrancea earthquake. Because of inadequate treatment of the concrete, the structure was damaged. The dynamic characteristics of the structure are investigated.

● 6.10-12 Galambos, T. V. and Mayes, R. L., **Dynamic tests of a reinforced concrete building,** *Structural Div. Research Report No. 51,* Dept. of Civil Engineering, Washington Univ., St. Louis, Missouri, June 1978, 240.

An eleven-story reinforced concrete building was subjected to a variety of dynamic tests during the period July through Nov. 1976. This report presents the description of these tests, summarizes data, and evaluates the results.

● 6.10-13 Martemyanov, A. I., **Consequences of 1976 and 1977 earthquakes in middle Asia and the effect of the foundation structural types on earthquake resistance of large-panel buildings,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-06, 1978, 41-46.

● 6.10-14 Medearis, K., **Rational damage criteria for lowrise structures subjected to blasting vibrations,** *Proceedings, The Institution of Civil Engineers,* Part 2, **65,** Sept. 1978, 611-621.

The development of more rational damage criteria for lowrise structures subjected to blasting vibrations is of significant importance. Maximum ground particle velocity guidelines have proved to be unacceptable. Such guidelines do not currently account for significant parameters such as the dynamic characteristics of the ground motion excitation and the structure being excited. However, data defining those characteristics are relatively limited. This paper describes an applied research effort in which such data were obtained, both experimentally and theoretically, for a reasonably large number of blasting ground motion recordings and existing lowrise structures. These dynamic characteristics were subsequently used in conjunction with available, reliable structural threshold damage data to develop rational damage criteria. These criteria have a strong theoretical and experimental basis and should be of significant value in predicting and preventing damage caused by blasting vibrations.

6.10-15 **Final report of 20-TBS Committee on testing building structures in situ** (in English and French), *Matériaux et Constructions,* **11,** *66,* Nov.-Dec. 1978, 457-475.

The development of new concepts of structural safety and the related extensive international cooperation on the scientific and economic aspects has led to the need to unify the principles of procedures which are followed in testing structures in situ. A first criterion in the design of a building structure is to provide a degree of strength in its members sufficient to ensure that collapse will not occur under any foreseeable loading incurred during its lifetime. Another criterion is a requirement of stability in the basic dimensions, calling for control of deformations in the structural components. It is not the purpose of this paper to present data satisfying various requirements, but to indicate the general information required to prepare the International Union of Testing and Research Labs. for Materials and Structures ("RILEM") recommendations of procedures that will follow. RILEM Technical Committee

20 Testing of Building Structures in-situ (TBS) collected in the last few years 33 standards, recommendations and rules of various European and overseas institutes and specialists and more than 50 reports, papers and other new information about recent experiences and results of field tests and long-time observations of structures or structural elements tested in situ. Information was obtained from the USA, South Africa, the Soviet Union, Australia, Argentina, France, West Germany, East Germany, Hungary, United Kingdom, Japan, Norway, Portugal, Romania, Spain, Sweden, Venezuela, Czechoslovakia, and other countries.

The standards, recommendations and testing rules can generally be divided into three main groups: (a) General rules covering in situ testing—some factors in the field testing of structures; general requirements for load tests and the experimental analysis of stress and strain propagation; static load testing of structures; dynamic load testing including impact tests; long-term observations of structures; special tests; tests of structural materials. (b) Recommendation or standards for seven main groups of structures; i.e., residential and school buildings; industrial buildings and special roofings; highrise buildings; bridges; roads and airfield pavements; dams; special structures (silos, water towers, reactors, etc). (c) Recommendations or standards for various TBS methods and measurements—nondestructive tests; geodetic methods; macroscale measurements; microscale measurements.

● **6.10-16** Masao, T. *et al.*, **Experimental and analytical studies of embedment effects on seismic response** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 52, Nov. 1978, 409–416.

This paper evaluates the dynamic characteristics of deeply embedded structures and verifies current analytical methods for the prediction of their seismic response. Forced vibration tests using an eccentric mass vibrator were performed at varying embedments on a rectangular prism model constructed of concrete (5 x 5 x 3.75 m in size; 173 t in weight). Earthquake observations were carried out on the model with concrete added up to 1.25 m above ground. An attempt was made to correlate the experimental results with the results determined by use of a lumped mass model and two finite element models (one having an extensive mesh and the other, a transmitting boundary). Embedment effects were considered. From the forced vibration test results, it was found that the resonant frequency increased linearly with embedment, while the damping ratio was nearly constant to a depth of 1.75 m. The damping ratio did increase greatly at lower depths, however. The lumped mass and the extensive mesh models showed good agreement with the experimental resonant frequencies, and the lumped mass and the transmitting models showed good agreement with the experimental damping ratios.

There were no significant differences between the seismic responses calculated with the analytical methods, and the theoretical results agreed with those of the observations. The ground vibration at the field site calculated using one of the models produced good results. No effects of soil-structure interaction were found in either the theoretical analyses or in the observations. This may have been because the mass ratio of the model was small. Both the analytical and the experimental work indicate that the effect of embedment can be incorporated into the seismic response analysis of structures using these analytical methods. In particular, the lumped mass and the transmitting boundary models can be used when the mass ratio of a structure is large.

● **6.10-17** Yamabe, K. and Kanai, K., **On the seismic characteristics of actual buildings. Case of the San Fernando earthquake (1971)** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 109, Nov. 1978, 865–872.

This paper concerns the seismic characteristics of actual buildings determined from analyses of the strong-motion earthquake records obtained in 17 steel and 37 reinforced concrete buildings during the San Fernando earthquake of Feb. 9, 1971. It was found that, the larger the number of stories above ground level, the larger the value of the maximum acceleration on the upper floor of the buildings. This tendency agrees with the shear coefficient of the building code of the Structural Engineers' Assn. of California. The average rates of increase of the predominant periods of the buildings during the earthquake compared with the natural periods of each building before the earthquake are 40% for steel buildings and 55% for reinforced concrete buildings. The average rates of increase of the natural periods of the buildings after the earthquake compared with those before the earthquake are 17 ~ 18%. Some results of the present investigation agree well with the theoretical results of the phenomena of the multiple reflection of waves in buildings as well as with the dissipation of vibrational energy of buildings to the ground. None of the observed results contradict the theoretical results.

● **6.10-18** Nakamura, M. *et al.*, **A study on the dynamic behavior of underground tank by a large-sized reinforced concrete model** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 119, Nov. 1978, 945–952.

Recently, many underground tanks have been constructed in Japan for the storage of crude oil and liquefied gas. It is very important to determine the dynamic behavior

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of underground tanks and the surrounding ground. For this reason, the authors constructed a model, a reinforced concrete structure of cylindrical shape 6 m in diameter and 3 m in depth, with a side wall and a slab-shaped shell of 15-cm thickness. Several vibration tests of the tank have been conducted.

This paper discusses the dynamic characteristics of the underground tank. Comparisons are made of experimental simulations using microtremor observations, explosive vibration test results, forced vibration test results, earthquake observations, and analytical simulations using a lumped-mass model and a three-dimensional finite element model. The following conclusions are obtained: (1) The peak of the frequency of the Fourier spectra obtained from microtremor observations and from earthquake observations appears only in the range from 1.4 Hz to 1.8 Hz, which is extremely close to the natural frequency of the ground. Therefore, the influence of the tank response is small and the motions of the underground tank are similar to the motions of the surrounding ground. (2) The strain of the tank wall obtained from the explosive test and from the earthquake observation has the same sign at opposite sides and a different sign at the other perpendicularly opposite sides. The tank is deformed ovally during the earthquake. (3) The result of the forced vibration test indicates that the response of the tank is influenced considerably by the depth of embedment. (4) The analytical results using the lumped-mass model and the three-dimensional finite element model agree well with the experimental results of the forced vibration test.

● **6.10-19** Kato, M. *et al.*, **Forced vibration tests at the Tokai No. 2 Nuclear Power Plant-part I: tests method & measurement results** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 182, Nov. 1978, 1449-1456.

The Tokai No. 2 nuclear power plant 1100 MWe BWR built by the Japan Atomic Power Company in Tokai is one of the largest plants in Japan. The reactor building is a tall, rigid, massive reinforced concrete structure. Its basemat is nearly square (70 m long). The building stands 56 m above ground and 17 m below ground. The weight is 280,000 tons. The reactor building design was carried out by means of dynamic seismic-resistant design procedures to ensure the highest degree of safety.

Vibration tests were used to investigate the safety of the design by measuring vibration characteristics of the actual reactor building and to obtain useful data for the seismic-resistant design of future reactor buildings. In this paper, the forced vibration test measurement data are presented. The two vibrators installed on the fifth floor of the reactor building were eccentric-mass-type vibrators capable of exciting a maximum horizontal force of 150 tons at 13 Hz. For this test the horizontal exciting force was kept constant at various eccentric moments. Accelerometers capable of recording 26 components were installed on each floor of the reactor building. Signals from respective measuring points were gathered in a measurement unit mounted on a data transaction container and recorded on magnetic tape.

The test results were represented as resonance curves and phase angles at every measurement point. Floor response curves were obtained from the averaged data of plural measurement points on each floor, and mode shapes for each peak of the floor response curves were determined. The first to third natural frequencies determined from the floor response curves and mode shapes of the reactor building coincided with numbers calculated in the design analysis. The modal damping values calculated by a general method from test data for the first natural frequency of the reactor building is approximately three times the number adopted in the design analysis. It therefore can be concluded that the design analysis included a satisfactory safety margin and that the reactor building would withstand a strong earthquake.

● **6.10-20** Hanada, K. *et al.*, **Forced vibration tests at the Tokai No. 2 Nuclear Power Plant (part 2): data reduction based on the modal analysis theory and its application** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 183, Nov. 1978, 1457-1464.

In this paper, a method is presented for determining from floor response curves each order of an eigenvalue and eigenvector (modal constants). The method also can be used to calculate random response from eigenvalues and eigenvectors. Modal constants are determined by applying nonlinear multiregression analysis to the transfer functions obtained from experiments, where regression curves are the function of modal superposition derived from modal analysis theory. The Taylor method used in this paper can be applied not only to a lightly damped system but to a system where the critical damping ratio reaches about 30%. In addition, the ratio converges faster with use of the Taylor method than with use of the modal circle method.

The Taylor method was applied to experimental results, and the computational results were compared with design values in order to examine the validity of the design and in order to obtain more reasonable data for seismic-resistant design. Complex transfer functions for each floor obtained from experiments were calculated by the superposition of each mode. These functions were reduced to modal constants. The modal constants were superimposed, and it was certified that these results gave good conformity with experimental results.

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It is concluded that the fundamental natural frequencies of the reactor building were in comparatively good agreement with those estimated from the design model and that the damping constants of the first mode of the building were estimated to be between 15%-25%, which was far larger than the design value of 5%. Using modal constants reduced from experimental response curves, the response to the El Centro earthquake also was calculated. For this case, the response of each floor was about 1/2 - 4/5 that of the design value.

● **6.10-21** Hirashima, S., Yamahara, H. and Watanabe, Y., **Forced vibration tests at the Tokai No. 2 Nuclear Power Plant-part 3: simulation analyses** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 184, Nov. 1978, 1465–1472.

For the simulation analysis of the dynamic behavior of a reactor building, the dynamic properties of the superstructure and the effects of soil-structure interaction must be estimated accurately. In this paper, a plant and its foundation soil were represented by a mathematical model, and simulation analyses were carried out to match the test results. The models obtained were employed for response analysis using design earthquakes. It was found that the seismic forces in the reactor building were smaller than those assumed in the design. After reviewing the typical characteristics found in the tests, the complex modal superposition method was adopted in the response analysis. The soil-structure interaction constants (stiffness, damping, and virtual mass) were determined using Tajimi's dynamic complex stiffness method. The cross interaction effect between the reactor building and the adjacent turbine building was evaluated on the basis of the theory of elasticity. The damping matrix was composed so as to preserve a constant damping ratio for all modes of the superstructure.

The simulation analyses were carried out for three different types of models, R, RS, and RTS. Type R, the simplest model, was composed of a reactor building and its foundation soil at the bottom. In addition to this, the soil-structure interaction effect on the side wall of the foundation was considered in the RS model. The cross-interaction effect between the reactor building and the adjacent turbine building was taken into consideration in the RTS model. It was found that for the R model it was difficult to simulate the resonance peak at the fundamental mode. The analytical models of Types RS and RTS and the suitable physical constants are shown. The resonance curves and the mode shapes at resonance are shown. These results seem to match those obtained from the experiment. The RTS model shows especially good agreement with the test result for the resonance frequency and for mode shapes at the second mode. This resonance mode seems to be caused by the cross-interaction effect, and the effect should be taken into account in the seismic design of nuclear power plants. The damping ratios of low-frequency modes could be estimated as 15 to 25 percent of the critical ratio. Design earthquakes were applied to the models determined from the simulation analyses and the peak accelerations, shear forces, and bending moments are compared with those of the design values.

● **6.10-22** Onose, J., Suzuya, J. and Kumagai, M., **The analytical and experimental study on the Nishigo Primary School damaged by '78.2.20 Miyagi-ken-Oki earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 186, Nov. 1978, 1481–1488.

The two-storied reinforced concrete Nishigo Primary School building was damaged seriously by the Miyagi-ken-oki earthquake on Feb. 20, 1978. This building was constructed in three stages from 1962 to 1974. The portion of the building constructed in each stage was placed in a straight line and connected only by girders. The framing plan is shown. The damage to this building is characteristic of its distribution; the damage to the first and third portions located at both ends of the building was more serious than the damage to the second portion. It is thought that this damage would be caused by the coupled vibration system effect resulting from the incomplete connections between each portion of the building.

The ultimate strength and the mode of failure are investigated in accordance with "The Recommendation of Seismic Proof Evaluation of Existing Reinforced Concrete Building" and the load-deflection characteristics of each portion of the building are evaluated. Comparing these results with the type of damage, it is determined that the magnitude of the seismic force to each portion apparently would be different such as $k = 0.5\text{-}0.6$ to the first and third portions and $k = 0.4$ to the second portion. To clarify the characteristics of the coupled vibration system, experiments were carried out. The vibration exciter was placed on the embedded concrete foundations. The resonance curves and the response curves of the absolute displacement are shown. An example of a record measured simultaneously at the second and third portions is examined. The mode shapes obtained from this experiment are shown. It is concluded that the building constitutes a coupled vibration system in the longitudinal direction because the three portions were not monolithically connected.

● **6.10-23** Suzuya, J. and Kawamata, S., **Studies on the damaged roof of a gymnasium due to 78' off Miyagi earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 189, Nov. 1978, 1505–1512.

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Damage to the roof of a gymnasium caused by the off-Miyagi earthquake of Feb. 20, 1978, was investigated; and a free vibration test of the roof was carried out. The roof has a square plan of 43 m x 43 m and is composed of a symmetrical two-way grid of latticed trusses. Tension fracture and inelastic buckling of the truss members occurred. The damaged members are classified according to the type of damage. Because of the symmetrical distribution of the damaged members, excessive vertical vibration was suspected. In an analysis, the roof structure was treated as a two-way grid system, the members of which have flexural and shearing rigidities equivalent to the latticed trusses. The vertical vibration mode of the grid was obtained; the first three modes have frequencies of 0.29 Hz, 0.25 Hz, and 0.22 Hz, respectively, and the measured frequencies of the roof were 0.21~0.23 Hz. Measured frequencies of the roof nearly equal 0.22 Hz, and phases of the measuring points are coincident with the third vertical vibration mode of the grid. From the test results and the analysis, it is assumed that the edge beams which support two edges of the roof cause the roof to oscillate.

● **6.10-24** Ohba, S., **Dynamic characteristics of multi story apartment buildings obtained from the measurement of microtremors** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 145, Nov. 1978, 1153-1160.

This paper studies the influence on the natural period of a building's shape and height and the condition of the ground. One hundred fifty-one apartment buildings considered in this study are of reinforced concrete or steel reinforced concrete and of 5 to 14 stories. The measured values obtained from microtremor records are compared with theoretical values for the rocking vibration of a rigid and a continuous shear type body on an elastic ground. It is found that the natural period for the longitudinal direction of the building tends to be a little longer than that for the transverse. In the longitudinal direction, however, the degree for fixing the rotation of the foundation seems higher. The relation of the measured natural period T (sec) and the height of building H (m) is represented as the following equation: $T = 0.012H + 0.055$. Measured natural periods agree with the theoretical values when the shear wave velocity Vs is assumed to be Vs = 150~300 m/sec, for a low and rigid-body building, and Vs = 200~400 m/sec, for a tall and continuous building. The measured natural period shows a tendency to decrease according to the increase of the N-value. The measured values are lower than the theoretical values. One of the reasons could be that the influence of the piles was not taken into account when estimating the ground stiffness. A vibration test was carried out on a 14-story building. These tests can be very useful for evaluating the stiffness, natural period, and damping characteristics of a structure.

● **6.10-25** Berardi, R. and Sano, T., **An investigation on the behavior of an instrumented multistory building in Maiano during the Friuli earthquake,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III,** 686-705. (For a full bibliographic citation, see Abstract No. 1.2-7.)

The behavior of a typical multistory building in Maiano, the area which suffered the most damage during the 1976 Friuli earthquake, is analyzed. The results from recorded data and structural dynamics studies are correlated in order to verify current analysis models. The stiffness of the exterior brick masonry walls is the main parameter governing the dynamic behavior of the building studied. Good agreement is obtained between the computed and recorded accelerations, demonstrating that it is possible, when the ground motion is specified, to make accurate predictions of building motion during moderate earthquakes by using a viscously damped linear model.

● **6.10-26** Celebi, M., Erdik, M. and Yuzugullu, O., **Harmonic vibration of some structures and natural periods,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 15-19.

By means of a vibration generator which supplies harmonic motion at controllable frequencies, it is possible to cause a structure to resonate at different modes and, thereby, determine the vibrational characteristics of the structure. This paper presents the experimental results of some structures tested by this method. Problems associated with testing of structures with joints are mentioned. Vibrational characteristics determined by various code formulas are compared.

● **6.10-27** Oppenheim, I. J., **High rise building vibration properties: an unexpected behavior mechanism,** *North American Masonry Conference Proceedings,* Paper No. 56, 15. (For a full bibliographic citation, see Abstract 1.2-12.)

Experimental and analytical studies were conducted of a 20-story reinforced masonry apartment building. The building, basically rectangular in plan, has 7 pierced shear walls in the short plan direction. All walls are constructed of two wythes of concrete block, enclosing a grouted core that contains the longitudinal reinforcement.

Acceleration records at roof level were obtained under ambient and man-induced vibrations. A fast Fourier transform of the ambient records provided frequency information in the E-W, N-S, and torsional directions. The man-induced vibrations provided direct observation of structural frequencies and a measurement of damping. Two elastic modal analyses of the building were performed by use of the program ETABS. In one analysis, the wall sections were considered to be coupled, while in the other, they were considered to be uncoupled. In the structure, the walls are uncoupled. Surprisingly, the measured building behavior was in exact correspondence with the coupled wall mechanism. The reason for this coupled wall behavior was apparent on closer examination. The detail for the lintel supports indicated that they should be embedded in the wall for a distance of 8 in. The bearing stress in the wall, acting over that embedment length, supplied a fixity moment to the lintel ends, transforming them from simply supported lintels into fixed-ended coupling girdles of limited capacity. Theoretical calculations of fixity moments, behavior under design loads, and recommendations for designers are presented.

● 6.10-28 Erdik, M., Yuzugullu, O. and Atalay, B., **Vibration of an 8-story R.C. building with brick infill walls** (8 katli tugla dolgu duvarli betonarme bir yapinin titresimi, in Turkish), Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, July 1978, 39.

In this study the dynamic behavior of the dormitory complex of the Turkish Military Academy in Kirazlidere, Ankara, is analyzed. The theoretical studies reveal the closeness of the first natural frequencies in the uncoupled lateral and torsional vibration modes of the building. The structure is symmetrical in the distribution of stiffness and mass. However, because of the forces generated by the friction at the construction joint between two units of the complex, the coupled lateral-torsional modes of one of the units is excited. This behavior is known as the "pseudo-resonance." The experimental results are compared with the theoretical analysis taking into account the soil-structure interaction. The asymmetric behavior observed is quantified by the introduction of a fictitious eccentricity.

● 6.10-29 Stephen, R. M. *et al.*, **Dynamic behavior of a pedestal base multistory building**, *UCB/EERC-78/13*, Earthquake Engineering Research Center, Univ. of California, Berkeley, July 1978, 156. (NTIS Accession No. PB 286 650)

As a part of a continuing program to evaluate the dynamic response of actual structures and to accumulate a body of information on the dynamic properties of structures, especially when these structures have novel design features, a dynamic test program was conducted on the 42-story Rainer Tower building in Seattle. This program also is aimed at evaluating the accuracy of computer modeling techniques and programs by comparing the experimentally derived dynamic response data with analytically predicted values. The dynamic tests of the building included both a forced vibration study and an ambient vibration study. These results are compared and, in general, show very good correlation. A mathematical computer model of the Rainer Tower was formulated, and the results of the analysis are presented and compared to the experimental results. In general, the results also compare very favorably.

● 6.10-30 Abdel-Ghaffar, A. M., **Vibration studies and tests of a suspension bridge**, *Earthquake Engineering & Structural Dynamics*, **6**, *5*, Sept.-Oct. 1978, 473-496.

The natural frequencies of the San Pedro-Terminal Island suspension bridge were fairly accurately determined by measuring traffic-excited vertical vibrations with seismometers mounted at various locations on the bridge. The Fourier amplitude spectrum of the recorded vertical movements are computed and plotted. The measurements reveal a wide band of natural frequencies. The results for the vertical and torsional natural frequencies are correlated with the computed frequencies. The results of the field measurements showed reasonable agreement with the computed values. Recommendations for methods of obtaining better results are indicated.

● 6.10-31 Taniwangsa, W., **Dynamic analysis of the structure utilizing microtremor measurement**, *Bulletin of the International Institute of Seismology and Earthquake Engineering*, **16**, 1978, 39-54.

The experimental and analytical study was conducted using the Indonesian Loading Code (P.M.I. 1970). For Jakarta, the maximum ground acceleration is 50 gals. A fixed-base structure was studied in the elastic range only. As an example, the Arthaloka building in Jakarta is analyzed.

6.11 Experimental Facilities and Investigations

6.11-1 Ghamian, M. M. and Sherbourne, A. N., **Continuous model mild steel beams under cyclic deflection**, *Materiaux et constructions*, **11**, *61*, Jan.-Feb. 1978, 21-30.

The load response of a section in an indeterminate structure when subjected to cyclic reversals of the strain-control type is predicted. The structure consists of a three-equal-span, continuous, rectangular, model mild-steel beam acted upon by a central load oscillating between predetermined deflection limits. The range of reversed central displacement may be symmetric or unsymmetric about the reference position. A moment-strain model is developed which predicts moment (load) variation with life N, delineating elastic or plastic response in the structure, depending upon the imposed deflection range. In cases where the mean deformation is relatively large compared with the imposed deformation range, the structure displays the ability to accommodate this input with little or no increase in the mean moment, thus reproducing the phenomenon of redistribution in a plastic hinge.

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● **6.11-2** Chung, H. W. and Lui, L. M., **Epoxy-repaired concrete joints under dynamic loads,** *Journal of the American Concrete Institute,* **75**, *7*, Title No. 75-34, July 1978, 313-316.

Dynamic shear tests were carried out on concrete push-off specimens which were severely damaged and then repaired by epoxy injection. The test results illustrate the effectiveness of the repair process in restoring the shear strength and the impulse capacity of the damaged joint.

● **6.11-3** Abrams, D. P., **Measured hysteresis relationships for small-scale beams,** *UILU-ENG-76-2030, Structural Research Series No. 432,* Univ. of Illinois at Urbana-Champaign, Urbana, Nov. 1976, 87.

Experimental results of cyclic load tests performed on small-scale beams are presented. The specimens are replicas of coupling beams used in a ten-story coupled wall model structure tested on the Univ. of Illinois earthquake simulator. Test variables are the reinforcement and the loading pattern. Descriptions of the fabrication process, test setup, instrumentation, and test procedures are presented. Measured moment-rotation relationships and patterns of crack development are used to describe the response and modes of failure of each specimen. The observed response is compared with that obtained from an analytical model representing deformations resulting from curvature, shear, and slip of the reinforcement.

● **6.11-4** Edwards, A. D. and Yannopoulos, P. J., **Local bond-stress-slip relationships under repeated loading,** *Magazine of Concrete Research,* **30**, *103*, June 1978, 62-72.

Pull-out specimens in which the reinforcing bar was embedded for 38 mm were tested under nine slow load cycles of constant amplitude to determine the effect of repeated loading upon the local bond-stress-slip relationships for deformed bars. The local bond-stress-slip curves obtained under repeated loading form hysteresis loops and have residual slip at zero load. The results show that bond effectiveness is particularly sensitive to the magnitude of the peak stress reached in preceding cycles. Load cycling of constant amplitude produces only a gradual deterioration of bond. The curves can be used for modeling a bond at the steel-concrete interface in finite-element analyses of reinforced concrete members.

● **6.11-5** Barney, G. B. *et al.,* **Earthquake resistant structural walls - tests of coupling beams,** Portland Cement Assn., Skokie, Illinois, Jan. 1978, 148.

Eight model reinforced concrete coupling beams were subjected to reversing loads similar to those that would occur in beams of coupled structural walls during a severe earthquake. The effects of selected variables on hysteretic response were determined. Controlled variables included the ratio of shear span to effective depth, reinforcement details, and size of the confined concrete core. Tests indicated that the hysteretic performance of beams with conventional reinforcement is limited by deterioration, resulting in sliding in the hinging region. Full-length diagonal reinforcement significantly improves the performance of short beams, but the improvement for long-span beams is less significant. Larger concrete core size improves load-retention capacity.

● **6.11-6** Cowell, A. D., Popov, E. P. and Bertero, V. V., **Repair of bond in R/C structures by epoxy injection,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-40, 1978, 297-303.

Two experiments were performed to determine the effectiveness of epoxy injection repair in restoring the bond of deformed reinforcing bars. Test specimens were designed to simulate the bond deterioration found in the interior beam-column joints of a reinforced concrete ductile moment-resisting frame subjected to severe lateral loads, such as those expected during major seismic ground motions. Two different epoxies and methods of injection were evaluated. Although the methods could restore sufficient bond strength to allow the application of sustained working stresses to the reinforcing bar, neither method was able to restore the full capacity of the bar.

● **6.11-7** Tomazevic, M., **Shaking table study of a simple reinforced concrete frame,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-10, 1978, 75-82.

The response of a simple reinforced concrete frame model, subjected to the ground displacements of the El Centro earthquake is studied. One-way static, cyclic, free vibration, and forced vibration tests were conducted. On the basis of preliminary test results, the mechanical properties of the structure are determined. These properties serve as the basis for the formulation of a mathematical model with the structure considered as a single-degree-of-freedom system. The response obtained is compared to the calculated response. Three different types of hysteresis loops are compared in the computation: classical bilinear elastoplastic model, bilinear stiffness-degrading model, and trilinear stiffness-degrading, zero-crossing model. Good results were obtained using the last two models, especially the trilinear stiffness-degrading, zero-crossing model.

● **6.11-8** Mihai, C. *et al.,* **Static and seismic behaviour of a large panel building of a lightweight granulite concrete,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-13, 1978, 101-110.

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Results are presented of experimental investigations carried out on a full-scale portion of an apartment building composed of lightweight panels. The building was tested on the large-capacity shaking table in Jassy. The results include the variation of lateral rigidities and dynamic characteristics for the different structural working stages, as well as parameters characterizing the total seismic response: accelerations, displacements, slidings, strains. The cracking process and the possibility of using lightweight granulite in structures located in seismic areas are discussed.

● **6.11-9** Rzhevsky, V. A. and Avanesov, G. A., **Studies of limiting state parameters for reinforced concrete frames beyond elastic limit,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-11, 1978, 83-90.

An experimental study was conducted on the elasto-plastic performance of reinforced concrete structural members (deflected and eccentrically compressed) and frame systems under dynamic and static sign-variable loads. Thirty-seven deflected members, six eccentrically compressed members, and three one-third-scale models of three-story frame buildings were tested as specimens. The tests made it possible to identify the limiting state parameters: the angle of rotation in plastic hinges, the energy-carrying capacity, and the relative and residual strains. Also established are the dissipative properties of the frame systems and the limits for dynamic parameter variations during failure development under sign-variable static and dynamic inelastic strains. The studies produced strain diagrams used as the basis for establishing the analytical dependence of the frame deformation law.

● **6.11-10** Diaconu, D. *et al.*, **Seismic testing of a five story RC structural model with platelike columns and slab floors,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-12, 1978, 91-99.

This paper describes the test of a five-story reinforced concrete model representing an apartment or office building consisting of monolithic platelike columns and precast flat slabs. The experimental program included base motions of progressively increasing intensity simulating one horizontal component of representative earthquake records, as well as free vibration and static tests to determine the dynamic characteristic variation and the lateral stiffness degradation at certain stages preceding failure. The objective of the investigation was to obtain experimental data on the behavior of the model when subjected to actual or simulated earthquake motions, and to correlate the data with prototypical analytical studies to facilitate the improvement of design.

● **6.11-11** Godden, W. G., **Seismic model studies of long-span curved bridges,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-26, 1978, 207-214.

This paper describes two recent shaking table studies on the seismic behavior of long-span curved highway bridges. The first study deals with a multi-span concrete bridge supported on a single line of columns, and this is discussed in detail. The second study deals with a proposed single-span curved cable-stayed steel girder bridge and is mentioned briefly. Experimental data is presented for the first study to show the principal dynamic characteristics. The potential benefits of horizontal curvature are indicated as well as certain problems that this generates.

● **6.11-12** Lu, L.-W. and Carpenter, L. D., **Hysteretic behavior of full-scale steel and composite frames,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-25, 1978, 199-206.

An experimental investigation of the hysteretic behavior of three full-scale steel frames and one composite frame is described. The frames were tested to study four specific problems related to earthquake-resistant design of buildings: the effects of beam flange buckling and of panel zone distortion on energy absorption, the strength of frames with columns oriented for minor axis bending, the behavior of frames with plastic hinges forming in columns, and the contribution of floors to frame strength. For each frame, the behavior observed during the test is discussed and sample hysteresis loops are given.

● **6.11-13** Gulkan, P. *et al.*, **An investigation on the seismic behavior of single-story masonry houses,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-15, 1978, 119-126.

Observations of the seismic behavior of a simple masonry house subjected to simulated earthquake motions are presented. The house was constructed so that similar masonry components were placed parallel and transverse to the table motion. Measurements indicated that the orientation of the timber trusses comprising the roof assembly, base fixity of the in-plane walls, and cracks which developed in the walls affected the overall response in a complex manner. In general, a nominal amount of reinforcement appeared to have a beneficial effect on preventing the formation of cracks which could lead to failure.

● **6.11-14** Delfosse, G. C. and Miranda, J. C., **Buildings on isolators for earthquake protection,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science

Foundation *et al.*, San Francisco, Vol. III, 1978, 1223–1233.

A strong revival of interest is observed currently in earthquake isolation technology. An aseismic building isolation system (ABIS) must satisfy four basic criteria of effectiveness. A particular type of ABIS, called the GAPEC system, was tested extensively at the Centre National de la Recherche Scientifique in Marseille, France, and at the John A. Blume Earthquake Engineering Center at Stanford Univ., California. Tests have shown that the GAPEC system satisfies the four basic criteria of effectiveness. Acceleration response, shears, and overturning moments are reduced by a factor of four to eight for buildings mounted on isolators. Isolation techniques are no more expensive than classical reinforcing systems, and different applications of ABIS have been put into practice.

6.11-15 Clough, D. P. and Clough, R. W., **Earthquake simulator studies of cylindrical tanks,** *Nuclear Engineering and Design,* **46,** *2,* Apr. 1978, 367–380.

An experimental investigation of the seismic response of ground-supported, cylindrical metal tanks is described. Experimental and analytical research by other investigators over the past 40 years has provided a basis for the computation of free- and forced-vibration behavior in ideal liquid-filled circular cylindrical shells with a variety of elementary support conditions. However, the actual seismic behavior of ground-supported tanks has not been known, and practical design methods necessarily have been based on simplifying assumptions. The present results provide the first opportunity for a rational evaluation of seismic design assumptions and suggest theoretical developments which would enhance the realism of seismic analyses.

The aluminum scale model discussed here, 12 ft in diameter and 6 ft high, represents a 36 ft diameter steel prototype. It was tested, in anchored and unanchored base configurations, under the action of a time-scaled El Centro, 1940, earthquake with a peak acceleration of 0.5g, using the earthquake simulator facility of the Univ. of California, Berkeley. Stresses and displacements of the model, in both anchored and unanchored conditions, were dominated by effects of "out-of-round" response in higher order circumferential modes, a result which is not predicted by current seismic analysis theory, and which contradicts basic assumptions of current design practice. The experimental observations are discussed in relation to dynamic analysis theory, practical design methods, and the history of tank performance in past earthquakes.

● **6.11-16** Verbic, B. and Terzic, N., **Behaviour of panel connections of multi-story large panel buildings under cyclic loading,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-27, 1978, 215–222.

Results are presented of cyclic shear load tests of typical panel connections in shear walls and load-carrying walls. The connections were tested in the complete range of deformations: prior to the shear failure of the connecting concrete and the loss of adhesion between the precast panels and the in situ cast concrete and afterward when large movements in the panel connection interfaces were allowed. Typical load displacement diagrams are given; and the effect of basic factors, such as shear friction or transverse reinforcement, on the connection behavior, is analyzed.

● **6.11-17** Augusti, G. *et al.*, **Tests of R.C. structural components subjected to repeated loads and repaired,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-18, 1978, 143–150.

Results are reported of an experimental program to evaluate the effectiveness of techniques for repairing reinforced concrete structures severely damaged by seismic loads. Portal frames were subjected to a harmonically varying horizontal force at the top beam levels. A specially mixed concrete was substituted in limited zones of the frames for the cracked concrete. After retesting under repeated loads, the repaired frames were found to be as strong and as ductile as the original frames.

● **6.11-18** Maruyama, K., Ramirez, H. and Jirsa, J. O., **Behavior of reinforced concrete columns under biaxial lateral loading,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-17, 1978, 135–141.

In designing structures for lateral loads, it is generally assumed that the direction of deformation coincides with a principal axis of the structure or member and with constant axial (generally compressive) forces on the columns. However, during recent earthquakes, some columns designed using these assumptions exhibited shear distress. The observed damage may be partially attributed to multidirectional forces during the earthquakes. This paper describes an experimental investigation of the influence of lateral loading history or sequence of application of bidirectional loads on the shear strength and hysteretic response of reinforced concrete columns.

● **6.11-19** Sheikh, S. A. and Uzumeri, S. M., **Concrete confinement by rectangular ties,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-22, 1978, 175–182.

The paper presents the results of a current research program at the Univ. of Toronto. The experimental program included testing of 24 short columns with cross sections of 12 in. by 12 in. (305 mm x 305 mm) and heights

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of 6 ft 5 in. (1960 mm). Columns were cast vertically and tested under monotonic axial compression. The core size of all specimens was 10.5 sq in. (267 mm). Examined are the effects on the load-carrying capacity and the ductility of confined concrete of such variables as the amount of longitudinal and lateral reinforcement, tie spacing, tie configuration, distribution of longitudinal steel around the perimeter of the core, and the characteristics of tie steel. A stress-strain relationship is developed for confined concrete. A comparison of experimental and predicted results shows very good agreement.

● **6.11-20** Mayes, R. L. *et al.*, **Cyclic loading behavior of masonry piers,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-10, 1978, 67–74.

Experiments were conducted to evaluate the seismic resistance of window piers typical of highrise masonry building construction. Thirty-one piers with a height-width ratio of one were subjected to cyclic shearing displacements in a test frame which provided suitable top and bottom boundary conditions. Principal test parameters were the amount and location of reinforcement, type of masonry unit, and the amount of grouting of the open cells. The main conclusions of the research are summarized.

● **6.11-21** Godden, W. G. and Aslam, M., **Dynamic model studies of Ruck-A-Chucky Bridge,** *Journal of the Structural Division, ASCE,* **104,** *ST12,* Proc. Paper 14206, Dec. 1978, 1827–1844.

The experimental prototype for this study is a 1300 ft (400 m) span box-girder bridge with a horizontal radius of 1500 ft (458 m). It is supported on 48 cables individually anchored to the canyon walls. The model scale was 1/200 and a distorted model was constructed to study the global behavior of the system to ground shaking applied in all three coordinates. Preliminary testing included the measurement of static live-load response, system damping, and natural frequencies and mode shapes. These are compared with the results of linear analysis. Shaking tests were conducted on a 20 ft x 20 ft (6.1 m x 6.1 m) two-component table. The principal dynamic behavior is shown in the form of time-history plots of selected quantities, and maximum response values are compared with linear analysis. It is concluded that linear analysis provides dynamic response data accurate enough for design purposes, that cable vibrations have little influence on the gross behavior of the system, and that the system damping is not appreciably affected by the cable system.

● **6.11-22** Moehle, J. P. and Sozen, M. A., **Earthquake-simulation tests of a ten-story reinforced concrete frame with a discontinued first-level beam,** *UILU-ENG-78-2014, Structural Research Series No. 451,* Univ. of Illinois, Urbana, Illinois, Aug. 1978, 162.

A small-scale, ten-story, reinforced concrete frame structure with relatively flexible lower stories was subjected successively to simulated earthquakes of increasing intensity on the Univ. of Illinois earthquake simulator. The test structure comprised two frames situated opposite one another with strong axes parallel to a horizontal base motion and with story masses spanning between. The frames had relatively tall first and last stories and a discontinued first floor-level, exterior-span beam. Earthquake simulation tests were complemented by free-vibration tests and steady-state sinusoidal tests at a series of frequencies bounding the apparent fundamental frequency. This report documents the experimental work, presents data (including time-response histories), and discusses the observed dynamic response in relation to stiffness, strength, and energy dissipation capacity.

● **6.11-23** Steinman, V., Anicic, D. and Zamolo, M., **Tests on the walls made by hollow brick blocks reinforced in horizontal mortar joints designed for seismic zones,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-33, 1978, 263–270.

Wall specimens approximately 1.0 by 1.0 m, with and without reinforcement in the horizontal mortar joints, made of Yugoslav-standard thin-webb hollow clay blocks, were tested. The walls were subjected to diagonal tension and tested under cyclic loading until failure occurred. High-quality mortar and high-strength brick-mortar bonds resulted in high static strength but also in brittle failure. The failures were caused by the lack of resistance of the blocks to main stresses and by the low compressive strength of the blocks.

● **6.11-24** Petrangeli, M. P. and Menesto, F., **The effects of low cycle loads on the bond in reinforced concrete,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-36, 1978, 287–293.

The behavior of high-strength reinforced concrete deformed bars under cyclic loading has been investigated experimentally for both unidirectional loads and reversed loads. Tests derived from standard beam test procedures have shown that there is a progressive deterioration in the load-slip relationship while the average adherence stress at failure, referred to as the compressive strength of the concrete, does not change significantly.

● **6.11-25** Shimazu, T., **Seismic design of secondary structures and their dynamic effects on the building,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 111, Nov. 1978, 881–888.

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This paper presents experimental studies conducted to establish a seismic design method for wall-type structures recently developed for storage or security rooms. Also presented are the results of a dynamic analysis conducted to determine the seismic design load for these secondary structures and their effects on a building. The wall-type structure consists of three elements: four side walls and a top slab, both multi-panels connected by means of welding or bolting, and steel beams. Horizontal load tests are conducted on the various kinds of walls and on the wall and top-slab assemblages (space structure). The horizontal resistance capacities are discussed. A case study of the seismic design of an actual security room is analyzed based on a multidegree-of-freedom system.

● 6.11-26 Ohtani, K. and Minowa, C., **Earthquake simulator test of reinforced concrete frame structures,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 181, Nov. 1978, 1441–1448.

This paper discusses tests of reinforced concrete structures conducted on the earthquake simulator at the Earthquake Engineering Lab. of the National Research Center for Disaster Prevention located at Tsukuba New Town. Two types of full-scale single-story, single-bay reinforced concrete frames were built on the shaking table. One frame weighed about 60 tons and the other weighed about 130 tons. Both frames were subjected to simulated and modified earthquake ground motions with intensities large enough to cause inelastic behavior and to change the dynamic properties of the frames. Test results for both frames are described including the yielding of the reinforcing steel bars and the overall frame response. The bilinear and trilinear analytical models used to evaluate the inelastic response are compared with the measured performance.

● 6.11-27 Wakabayashi, M. *et al.*, **Experimental study on the elastic-plastic response of steel frames under dynamic excitation by means of a shaking table,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 180, Nov. 1978, 1433–1440.

Dynamic failure tests of small-scale models of single-story steel frames and braced frames were conducted on a shaking table at the Disaster Prevention Research Inst., Kyoto Univ. Elastic-plastic response and the failure process of model structures were examined under table motion simulated to the N-S component of the El Centro 1940 acceleration record, after having been subjected to small-amplitude sinusoidal wave motion to obtain the fundamental dynamic properties. Dynamic response analysis is also performed using a bilinear model for the hysteretic characteristics of columns and formulated hysteresis loops for the braces. From comparison of the test and analytical results, it is shown that the time history of the acceleration response of a model specimen is predicted with sufficient accuracy by the response analysis, and that the time history of the response for a story drift derived analytically does not agree well with the experimental results. This lack of agreement is primarily the result of an inaccurate estimate of the inelastic flow amplitude in the plastic deformation region of the hysteretic characteristics. It should be noted, especially for structures with negative slopes in the plastic range, that a slight difference in the input acceleration amplitude leads to a serious difference in the magnitude of plastic flow.

● 6.11-28 Hegemier, G. A., Nunn, R. O. and Arya, S. K., **Behavior of concrete masonry under biaxial stresses,** *North American Masonry Conference Proceedings,* Paper No. 1, 28. (For a full bibliographic citation, see Abstract 1.2-12.)

Biaxial tests of full-scale concrete masonry panels under monotonic and cyclic stress histories are described. The experimental results presented concern planar material behavior and are related to the formulation of constitutive relations for concrete masonry in both linear and nonlinear ranges of deformation. Topics discussed include: (1) the initial macrocracking or yield surface in the stress space; (2) macrocracking and isotropy; (3) prediction of the initial macrocracking surface and post-macrocracking behavior from component data; (4) influence of reinforcing steel on initial and post-macrocracking behavior; (5) elastic moduli and anisotropy; (6) elastic moduli and strength; (7) damping or energy absorption; and (8) strain-rate effects. Analytical models for certain of the above items are proposed. These tests are part of an extensive Univ. of California, San Diego, research effort on the seismic response of concrete masonry structures; they constitute the first biaxial experiments on masonry. A brief description of the associated test setup, which is unique in size and sophistication, is provided.

● 6.11-29 Hegemier, G. A. *et al.*, **On the behavior of joints in concrete masonry,** *North American Masonry Conference Proceedings,* Paper No. 4, 22. (For a full bibliographic citation, see Abstract 1.2-12.)

Joints or interfaces in concrete masonry assemblies constitute planes of weakness and a major source of stiffness degradation and damping. Failures frequently initiate in joints, and subsequent deformation and energy absorption may occur by relative slip across joint planes. Thus, data on joint fracture and post-fracture behavior is a prerequisite to a basic understanding of failure processes in concrete masonry. This paper presents selected results from a test program on joints in concrete masonry. Joint types selected for study include ungrouted bed joints, grouted bed joints, and head joints. Test specimens consist primarily of triplets (three blocks, two interfaces). Joint planes are subjected to constant levels of normal stress and both

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monotonic and cyclic shear stress. In each test, the initial and post-fracture shear stress versus normal stress envelopes and deformation histories are determined. Experimental results are supplemented by analytical and numerical studies.

● **6.11-30** Colville, J. and Ramseur, R., **The interaction of masonry wall panels and a steel frame,** *North American Masonry Conference Proceedings,* Paper No. 15, 13. (For a full bibliographic citation, see Abstract 1.2-12.)

A series of tests of prefabricated brick masonry wall panels, constructed with a high-bond strength, saran polymer mortar additive and a single-story, single-bay steel frame, subjected to lateral racking forces were conducted in order to investigate the contribution of nonstructural cladding of curtain wall panels to the lateral-load resistance of framed structures. Nine load tests were performed. The major variables in the test program included the magnitude of lateral load and the number of connectors used to attach the wall panel to the frame. The results indicate that a considerable amount of load transfer can exist and that between 30% and 40% of the lateral load is transferred to the nonstructural wall panels.

● **6.11-31** Hatzinikolas, M., Longworth, J. and Warwaruk, J., **The effect of joint reinforcement on vertical load carrying capacity of hollow concrete block masonry,** *North American Masonry Conference Proceedings,* Paper No. 16, 16. (For a full bibliographic citation, see Abstract 1.2-12.)

The effectiveness of wire joint reinforcement in load-bearing masonry is experimentally evaluated. Tests on prisms and full-scale walls were conducted under axial and eccentric loads. As joint reinforcement, #9 gauge, truss-type wire was used in two forms: as supplied (normal) and flattened to 60% of the original diameter. All reinforced specimens failed at lower loads than the plain specimens. Those reinforced with normal reinforcement exhibited lower failure loads than those with flattened reinforcement. The reduction in capacity is attributed to stress concentrations produced by the joint reinforcement.

● **6.11-32** Mayes, R. L. *et al.,* **Seismic research on multistory masonry buildings; University of California, Berkeley, 1972 to 1977,** *North American Masonry Conference Proceedings,* Paper No. 53, 19. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper describes the scope and provides a summary of the results of the seismic research program on multistory masonry buildings that has been conducted at the Earthquake Engineering Research Center, Univ. of California, Berkeley, since Sept. 1972. The program has consisted of two major phases. The first phase consisted of 17 in-plane shear tests on a double-piered concrete block test specimen. The second phase, which is still in progress, consists of 80 in-plane shear tests on a single pier test specimen. The tests include hollow concrete block, hollow clay brick, and grouted core clay brick specimen. The paper includes a section on the design implications of the results obtained to date in both the Berkeley test program and a similar test program being performed in New Zealand.

● **6.11-33** Gulkan, P. *et al.,* **An experimental investigation on the seismic behavior of single-story masonry houses,** *North American Masonry Conference Proceedings,* Paper No. 54, 20. (For a full bibliographic citation, see Abstract 1.2-12.)

Observations of the seismic behavior of a simple masonry house subjected to simulated earthquake motions on the Univ. of California, Berkeley, shaking table are presented. The house was constructed so that similar masonry components were placed both parallel and transverse to the table motion. Measurements indicated that the orientation of the timber trusses comprising the roof assembly, the base fixity of the in-plane walls, and the cracks which developed in the walls affected the overall response in a complex manner. In general, a nominal amount of reinforcement appeared to have a beneficial effect on preventing the formation of cracks that could lead to failure. Additional pseudo-static tests were conducted on typical timber roof-masonry wall connection details to assess their adequacy for resisting seismic forces.

● **6.11-34** Keightley, W. O., **Low cost facility for testing the ultimate earthquake resistance of masonry structures,** *North American Masonry Conference Proceedings,* Paper No. 50, 15. (For a full bibliographic citation, see Abstract 1.2-12.)

A 6 m by 7 m table, which can impart shocks in the form of horizontal half-sine acceleration pulses to the foundations of 20-ton structures, has been constructed around the frame of a railway wagon. The shocks, of 0.1 sec duration and up to 2 g amplitude, are generated by impacts caused by two heavily loaded wagons that roll down short inclines and collide with the heavy springs of the platform wagon. Tests of half-scale models of one-room, low-grade masonry houses reveal the weakness of walls that are transverse to the shocks and demonstrate the effectiveness of vertical steel bars in the building corners and the effectiveness of encircling reinforced concrete bands at lintel level. The tests also raise questions about the anchorage of corner reinforcing bars in the foundation. A proposal is made for construction of a similar facility capable of shaking to collapse structures weighing from 100 to 200 tons.

● **6.11-35** Muto, K. *et al.,* **Structural test and analysis on the seismic behavior of the reinforced concrete reactor**

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building (Part 1: test result and analysis) (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 35–42.

A reactor building is a large structure consisting of thick walls and thick slabs. As the first step in establishing a rational seismic-resistant design procedure and construction method for such a structure, a BWR Mark II was chosen as a prototype. The object of the experiment was to study the overall behavior of the reactor building under earthquake forces. The specimen was a vertically split 1/25-scale model to which lateral forces were applied statically. The test clarified the strength and deformation relationship, the mode of failure, and the safety factors for the design load. The model failed in shear as anticipated, but possessed unexpected toughness and strength. The formula proposed by the authors for the strength-deformation relationships, which correspond moderately with other existing analytical load-deformation curves, well represents the test results of the thick-walled structure.

● **6.11-36** Kato, B., Akiyama, H. and Kitazawa, S., **Deformation characteristics of box-shaped steel members influenced by local buckling** (in Japanese), *Transactions of the Architectural Institute of Japan, 268,* June 1978, 71–76.

In this paper, the results are discussed of an experimental investigation of the effects of local buckling on the inelastic behavior of steel members with box-sections. Three tests were conducted: a stub-column test, a beam test, and a beam-column test. The principal geometric parameters of the specimens used were the width-to-thickness ratio of the plate element and the slenderness. It was found that the most fundamental loading condition for beam-columns subjected to earthquakes is the combined axial compression and end moment coupling which produces flexural deformation with double curvature. Results of the three types of tests are summarized by simple empirical formulas which provide whole load-deformation curves of the members under the fundamental loading condition.

● **6.11-37** Suzuki, T., Tamamatsu, K.-I. and Kubodera, I., **Experimental study on the elasto-plastic behavior of three dimensional frames (studies on seismic resistivity of low steel structures, part 2)** (in Japanese), *Transactions of the Architectural Institute of Japan, 265,* Mar. 1978, 33–43.

The three-dimensional elastoplastic behavior of space frames was studied experimentally. The frames consisted of two rigid frames in one direction and two tensile braced frames in the other direction. The test specimens were one-story, one-bay space frames constructed with four columns and four beams of H-shaped members with four tensile braces of round steel. These frames were tested under horizontal and axial loading. The following differences in the elastoplastic behavior of space frames and plane frames were found: (1) The additional axial force in the columns caused by the deformation of the braced frames affects the restoring forces of the two parallel rigid frames, and torsion accumulates in the frame with repetition of the loading cycles. (2) The maximum restoring force and plastic deformation capacity in the direction of the strong axis of H-shaped columns decrease under the influence of column deformation in the direction of the weak axis.

● **6.11-38** Inoue, K. and Murakami, M., **A study on the plastic design of braced multi-story steel frames (Part 3: experimental study on the elastic plastic behavior of 3 story 3 bay braced and unbraced steel frames)** (in Japanese), *Transactions of the Architectural Institute of Japan, 271,* Sept. 1978, 45–51.

Experimental results of 3-story, 3-bay braced and unbraced frames under monotonic or alternating horizontal forces are shown in this paper. Four specimens were tested, two braced frames and two unbraced frames. Both are designed against the same factored horizontal forces, and individual members are processed to have a net strength. Test frames are subjected to horizontal forces proportional to design forces at each floor level.

The force-deflection curves do not differ markedly from test results reported by many investigators. In the case of the braced frames, the bracing members of the lowest story have the smallest ratio of story shear-force shared by the bracings to the total shear force buckle and yield at the outset, so that the relative story displacement of the lowest story increases before buckling and yielding develop in all other bracing members. After this happens, however, the relative story displacement of each story increases uniformly. This result suggests that the bracing members should be designed so as to buckle or yield simultaneously against seismic force. Experimental force-deflection curves are well predicted by the generalized hardening hinge method.

● **6.11-39** Sonobe, Y. *et al.*, **Research of failure mechanisms of frames with shear walls (experiments on two frames of differing shear wall arrangements)** (in Japanese), *Transactions of the Architectural Institute of Japan, 272,* Oct. 1978, 21–29.

The effects of wall arrangements on the failure mechanisms of frames with shear walls are studied. Checkered and multistory arrangements are tested and found to fail differently under lateral forces. For a frame with multistory shear walls, the bending shear failures of the boundary beam and the frame column connections between two coupled walls precede the collapse ultimately produced by the yielding in flexure of the shear walls. In contrast, for a frame with checkered shear walls, the entire frame resists the external force as a single unit until very close to the

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maximum load when shear failure occurs at the inner spans of the walls.

● 6.11-40 Hidalgo, P. A. *et al.*, **Cyclic loading tests of masonry single piers, Volume 1 - height to width ratio of 2,** *UCB/EERC-78/27,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1978, 140. (NTIS Accession No. PB 296 211)

This report presents the results of fourteen cyclic, in-plane shear tests on fixed-ended masonry piers having a height to width ratio of 2. These fourteen tests form part of a test program consisting of eighty single pier tests. Subsequent reports will present test results of the additional sixty-six tests. Each subsequent report will be based on the height to width ratio of the 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 80 inches high and 40 inches wide. Two types of masonry construction were used: a hollow clay brick type that used an 8 inch wide unit, and a double wythe grouted core clay brick, 10-inch thick wall, that consisted of two wythes 3 1/2-inches thick and 3-inch grouted core. The variables included in the investigation were the quantity of reinforcement and the type of grouting.

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.

● 6.11-41 Chen, S.-W. J. *et al.*, **Cyclic loading tests of masonry single piers, Volume 2 - height to width ratio of 1,** *UCB/EERC-78/28,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1978, 188. (NTIS Accession No. PB 296 212)

This report presents the results of thirty-one cyclic, in-plane shear tests on fixed-ended masonry piers having a height to width ratio of 1. These thirty-one tests form part of a test program consisting of eighty single pier tests. A previous report presented the results of fourteen tests of piers having a height to width ratio of 2, and subsequent reports will present the test results of the remaining thirty-five tests.

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 56 in. high and 40 in. wide. Three types of masonry construction were used: hollow concrete block and hollow clay brick, both with 8-in.-wide units, and a double wythe grouted core wall, 10 in. thick, that consisted of two clay brick wythes 3 1/4 in. thick and a 3 1/2 in. grouted core. The other variables included in the investigation were the quantity of reinforcement and the type of grouting.

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 the 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.

6.11-42 Vitelleschi, S. and Schmidt, L. C., **Influence of cyclic loading on the slip factor for friction-grip joints,** *Civil Engineering Transactions,* CE **20**, 2, 1978, 112–119.

The paper concerns the influence of cyclic loads on the slip factor for high-strength, friction-grip bolted joints. Static and cyclic load tests on specimens with four different surface finishes are described, namely, galvanized, mill scale, urethane chromate primer, and an inorganic zinc silicate coating. The first three surfaces furnish an increase in their associated slip factors for cyclic loads less than their initial static slip-load values. Three variable programs of cyclic loading were used; the frequency of loading was 0.6 Hz. Reference is made to bolt tension losses.

● 6.11-43 Mayes, R. L., Omote, Y. and Clough, R. W., **Cyclic shear tests of masonry piers, Volume 2 - analysis of test results,** *EERC 76-16,* Earthquake Engineering Research Center, Univ. of California, Berkeley, 77.

This report presents an analysis of the results of the tests described in EERC Report 76-8 (*AJEE,* Vol. 6, Abstract No. 6.11-59). The critical tensile strengths obtained from double pier tests are compared with those obtained from a simple diagonal compression test on a square panel. The report also contains idealized hysteresis envelopes developed from the experimental results for the two primary modes of failure observed in the test series. Also included in this chapter are theoretical methods for calculating the ultimate shear and flexural capacities of the piers. The capacities obtained from the theoretical methods are compared with the experimental results; good agreement is obtained for the flexural capacity, whereas the method used for the shear mode of failure overestimates the experimentally determined values. The results obtained in this test program are compared with those of other investigations.

● 6.11-44 Suzuki, S., Sugiyama, H. and Noguchi, H., **Behavior of the bearing wall in the wooden North-American-type full-size building (no. 2) (in Japanese),**

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Transactions of the Architectural Institute of Japan, 271, Sept. 1978, 15–26.

This paper describes results of racking tests on bearing walls. Examined is the influence of racking test methods and wall width on the shearing properties of a wall with a tension wood brace, a wall with a compression wood brace, and a plywood-sheathed wall with a tension wood brace.

● **6.11-45** Niwa, A., **Seismic behavior of tall liquid storage tanks,** *UCB/EERC-78/04,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1978, 330. (NTIS Accession No. PB 284 017)

This report discusses the results of an experimental program in which a scaled model of a ground-supported, thin-shell, cylindrical liquid storage tank with a height greater than the radius was subjected to simulated earthquake excitation. Analytical investigations of out-of-round shell deformation of cylindrical tanks are also discussed. This experimental program was the second phase of a research project in which various scaled tank models were tested to assess the applicability of current seismic design practice to ground-supported, thin-shell, cylindrical liquid storage tanks. The first phase of the research considered "broad" tanks.

The methods, model, and facilities used in the experimental evaluation of the seismic behavior of tall tanks are described. The principal results of this experimental investigation are presented in the form of a critical evaluation of current seismic design practice. It is observed that a significant out-of-round deformation response is induced in addition to a cantilever beam-type response, while typical design procedures assume the critical seismic response mechanism in ground-supported tanks is a quasi-static overturning effect, without distortion of the circular cross section.

The development of an analytical procedure illustrating a possible correlative mechanism between the initial geometric eccentricity in the cross section of the tank model and the out-of-round shell deformation is described in detail. The results demonstrate that one of the most important causative mechanisms of out-of-round deformation response of the cylindrical tank is related to dynamic variations of the membrane hoop force developed in the shell circumference.

● **6.11-46** Eidinger, J. M. and Kelly, J. M., **Experimental results of an earthquake isolation system using natural rubber bearings,** *UCB/EERC-78/03,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1978, 55. (NTIS Accession No. PB 281 686)

This report describes the experimental results of a series of earthquake simulation tests on an earthquake isolation system based on natural rubber bearings. Three forms of isolation system were used. Since the primary purpose of the test program was to examine the effect of damping in the isolation system, the essential difference between the three forms was the level of the damping in the system. A large number of simulated earthquake motions were used in the tests, including El Centro 1940, Taft 1950, Parkfield 1966, and Pacoima Dam 1971. The natural rubber bearings reduced the forces and overturning moments to approximately one-tenth of those in a conventionally fixed structure, and the results demonstrated the practical possibility of this type of isolation system for full-scale buildings.

● **6.11-47** Umemura, H., Aoyama, H. and Noguchi, H., **Experimental studies on reinforced concrete members and composite steel and reinforced concrete members** (in English and Japanese), Dept. of Architecture, Univ. of Tokyo, Tokyo, Dec. 1977, 2 vols., 408.

● **6.11-48** Tyler, R. G., **A tenacious base isolation system using round steel bars,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11**, *4,* Dec. 1978, 273–281.

The tenacity of reinforcing bars in resisting earthquake loading, after the spalling of concrete around the bars, suggests that round bars can be used to dissipate earthquake energy in base isolated buildings, provided a bow is introduced in the bars to allow them to extend as the building deflects on its bearings. Dynamic tests from which a design method for such a system can be developed are described. The method has the advantage of simplicity in that round bars available in normal engineering practice can be utilized. A tensile capacity is introduced between the structure and the foundation which enables the system to lock progressively under disaster conditions.

● **6.11-49** Otani, S. and Tang, C. S., **Behavior of reinforced concrete columns under biaxial lateral load reversals–(1) pilot test,** *78-03,* Dept. of Civil Engineering, Univ. of Toronto, Feb. 1978, 126.

This paper examines the behavior of a reinforced concrete column under biaxial lateral and axial load reversals in order to gain an understanding of the behavior of a reinforced concrete structure during an actual earthquake. On the basis of the test results reported, the following conclusions are drawn: (1) The effect of biaxial lateral load reversals on the behavior of reinforced concrete columns exists prior to the tensile yielding of the longitudinal reinforcement; (2) In the specimens tested, the effect of biaxial lateral load reversals is relatively small after the tensile yielding of longitudinal reinforcement; (3) If the ductility of a member is required under lateral load reversals, the welding on of a longitudinal reinforcement should not be permitted near the critical section; and (4) Further experimental research is needed to study the effect of biaxial lateral load reversals on the behavior of reinforced concrete columns with high shear and/or high axial loads.

6.12 Deterministic Methods of Dynamic Analysis

● 6.12-1 Miller, R. K. and Iwan, W. D., **The peak harmonic response of locally non-linear systems**, *Earthquake Engineering and Structural Dynamics*, **6**, *1*, Jan.-Feb. 1978, 79-87.

This paper presents an approximate analytical technique for determining the steady-state response of a class of systems with spatially localized nonlinearity. A method of finding the amplitude peaks in various modes is presented. Numerical examples illustrate the nature and accuracy of the approximate analysis results.

● 6.12-2 Hilber, H. M. and Hughes, T. J. R., **Collocation, dissipation and 'overshoot' for time integration schemes in structural dynamics**, *Earthquake Engineering and Structural Dynamics*, **6**, *1*, Jan.-Feb. 1978, 99-117.

The concept of collocation, orginally used by Wilson in the development of dissipative algorithms for structural dynamics, is systematically generalized and analyzed. Optimal schemes within this class are developed and compared with a recently proposed family of dissipative algorithms, called α methods. The α methods are found to be superior on the basis of standard measures of dissipation and dispersion. It is pointed out that the tendency to overshoot is an important and independent factor which should be considered in an evaluation of an implicit scheme. The basis for studying overshoot is discussed, and the optimal collocation and α methods are compared. It is found that pathological overshooting is an inherent property of collocation schemes, whereas the overshooting characteristics of the α methods are good.

● 6.12-3 Atalik, T. S., **An alternative definition of instructure response spectra**, *Earthquake Engineering and Structural Dynamics*, **6**, *1*, Jan.-Feb. 1978, 71-78.

Because of their relatively small mass, the components and equipment in a power plant do not affect the overall response of the supporting structure and so are not included in the dynamic model of the building. The design of such secondary systems depends on the response characteristics of the locations to which they are attached. In general, these response characteristics are described by instructure response spectra. Most commonly, the instructure response spectra are developed using a time-history analysis with a synthetic spectrum consistent accelerogram used as input. However, there is more than one spectrum-compatible ground acceleration record and each may give quite different instructure spectra. A way of overcoming this uncertainty could be to average the structural responses to several such inputs, but this is economically infeasible.

Besides the time-history analysis technique, there are some simplified procedures for the construction of instructure response spectra. These methods are based on the concept of amplification of the ground design spectrum. The one developed by Biggs is empirical in nature. Kapur and Shao modified Biggs' method into a mathematically more consistent form. Both methods yield conservative results in comparison to time-history solutions. Singh has proposed an approach based on random vibration theory, but it requires a spectrum-consistent power spectral density function.

In this study, an analytical redefinition of instructure response spectra is made. It is shown that a floor spectral value corresponding to a simple oscillator damping and frequency is equal to the maximum response of that floor when the structure is excited by a base motion obtained by filtering the prescribed ground motion through the oscillator. Then, utilizing the alternative definition formulated, the author proposes a procedure consistent with the concept of the design response spectrum for the generation of instructure response spectra.

● 6.12-4 McNiven, H. D. and Matzen, V. C., **A mathematical model to predict the inelastic response of a steel frame: formulation of the model**, *Earthquake Engineering and Structural Dynamics*, **6**, *2*, Mar.-Apr. 1978, 189-202.

Experimental data is used to formulate a mathematical model to predict the nonlinear response of a single-story steel frame to an earthquake input. The process used is system identification. The form of the model is a second-order nonlinear differential equation with linear viscous damping and Ramberg-Osgood-type hysteresis. The damping coefficient and the three parameters of the hysteretic model are to be established. An integral weighted mean squared error function is used to evaluate the goodness of fit between the model's response and the structure's response when both are subjected to the same excitation. The function includes errors in displacement and acceleration and is integrated from zero to a time T, which may be the full duration of the recorded response or only a portion of it. The parameters are adjusted using a modified Gauss-Newton method until the error function is minimized. The computer program incorporating these steps in the system identification process is verified with simulated data. Results show that in every case the program converges in few iterations to the assigned set of parameters.

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● **6.12-5** Powell, G. H., **Seismic response analysis of above-ground pipelines,** *Earthquake Engineering and Structural Dynamics,* **6,** *2,* Mar.-Apr. 1978, 157–165.

A procedure for computing the seismic response of above-ground, cross-country pipelines is described. The procedure accounts for the effects of initial static loads, slipping of the pipe on its supports, and out-of-phase ground motions at different points along the pipe. The idealization, assumptions, and theory are described, and an example illustrating the influence of several parameters on the response is presented.

● **6.12-6** Ku, A. B., **The K-quotient,** *Journal of Sound and Vibration,* **60,** *1,* Sept. 8, 1978, 63–69.

The Rayleigh quotient and a recently proposed Timoshenko quotient are upper bounds to the fundamental eigenvalue of a discrete dynamic system. The closeness of these upper bounds to the fundamental eigenvalue depends on the closeness of the trial vectors to the eigenmode used in the calculation. In this paper, a new quotient is presented which does not require the closeness of the trial vector to the eigenmode. Its accuracy can be improved by raising the numerical value of the parameter p.

● **6.12-7** Curiskis, J. I. and Valliappan, S., **A solution algorithm for linear constraint equations in finite element analysis,** *Computers & Structures,* **8,** *1,* Feb. 1978, 117–124.

A general solution algorithm is presented for incorporating a general set of linear constraint equations into a linear algebraic system; such situations arise when applying the finite element method to a variety of physical problems. Implementation of the algorithm, without need for prearranging the equations, into an equation solver using Gaussian elimination is developed. The method is preferable to other approaches for constrained systems.

● **6.12-8** Gurujee, C. S. and Deshpande, V. L., **An improved method of substructure analysis,** *Computers & Structures,* **8,** *1,* Feb. 1978, 147–152.

The substructure method is an established way of overcoming the difficulty of large dimensionality in analyzing structures. An improved substructure analysis method suitable for such structures as multistory buildings and towers is presented in this paper. The method is based on the peculiar geometry of these structures which can be used for numbering the boundary joints for a substructure either in the beginning or towards the end. Extra advantage can be taken of the substructues that are identical in terms of geometry and loading or in terms of geometry alone. Special static condensation and substitution routines are developed. The method is shown to be more efficient than any of the other substructure analysis methods.

● **6.12-9** Dawe, D. J., **A finite element for the vibration analysis of Timoshenko beams,** *Journal of Sound and Vibration,* **60,** *1,* Sept. 8, 1978, 11–20.

A Timoshenko beam finite element is presented which has three nodes and two degrees-of-freedom per node, namely the values of the lateral deflection and the cross-sectional rotation. The element properties are based on a coupled displacement field; the lateral deflection is interpolated as a quintic polynomial function, and the cross-sectional rotation is linked to the deflection by specifying satisfaction of the governing differential equation of moment equilibrium in the absence of the rotary inertia term. Numerical results confirm that this procedure does not preclude convergence to true Timoshenko theory solutions since rotary inertia is included in lumped form at element ends. The new Timoshenko beam element has good convergence characteristics, and, where comparison can be made in numerical studies, it is shown to be generally more efficient than previous elements.

● **6.12-10** Scharpf, D. W., **A new method of stress calculation in the matrix displacement analysis,** *Computers & Structures,* **8,** *3/4,* May 1978, 465–477.

In the stiffness factor formulation of the matrix-displacement method, the stresses can be directly deduced from the intermediate result of the forward substitution involved in the solution of the linear system of equations. While prior use of the factor method only resulted in a reduction of the numerical error in the displacements, the new formulation also permits the calculation of extremely accurate stresses, even in most ill-conditioned systems. The paper presents the derivation of the procedure, its theoretical interpretation, and the analysis of numerical error. It is shown that the latter is significant only in situations which are unlikely to occur in practice. All theoretical developments are illustrated by detailed calculations of trivially simple systems. Realistic structures are analyzed in order to prove the theoretical conclusions.

● **6.12-11** Johnsen, Th. L., **A numerical method for eigenreduction of non-symmetric real matrices,** *Computers & Structures,* **8,** *3/4,* May 1978, 399–402.

A numerical method for eigenreduction of a nonsymmetric real matrix is developed. This method is particularly advantageous in connection with vector iteration as applied to large matrices.

● **6.12-12** Mishu, F. and Marshall, J., **Numerical stability of complex finite elements,** *Computers & Structures,* **8,** *2,* Apr. 1978, 259–264.

The use of complex finite elements is economical in computing time, but there is an inherent danger that numerical instability can arise during the formulation of

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the stiffness matrix for such elements. This problem is studied with particular reference to rectangular plane-stress elements for which any number of nodes along a side may be prescribed. It is shown that the occurrence of numerical instability is directly related to the degree of the polynomial assumed for the displacement function and to the number of significant figures used in the calculation. The particular matrix operations which are susceptible to error are indicated.

● **6.12-13** Friedrich, C. M., **Calculation of the stress-strain stiffness matrix for given strains in an inelastic material,** *Computers & Structures,* 8, *2,* Feb. 1978, 265-268.

In the implicit method of nonlinear analysis of stiffness matrices of finite elements, deflection fields and hence strains are assumed to be known at one stage of the calculations. A procedure is developed to calculate the stress-strain stiffness matrix from the strains without iteration of the stress components when the material is inelastic.

● **6.12-14** Hughes, T. J. R. and Taylor, R. L., **Unconditionally stable algorithms for quasi-static elasto/visco-plastic finite element analysis,** *Computers & Structures,* 8, *2,* Apr. 1978, 169-173.

A new one-parameter family of implicit algorithms for quasistatic elasto/viscoplastic finite element analysis is proposed. For appropriate values of the parameter, the algorithms are shown to be unconditionally stable. Numerical tests confirming the theory are presented.

● **6.12-15** Soedel, W. and Dhar, M., **Difficulties in finding modes experimentally when several contribute to a resonance,** *Journal of Sound and Vibration,* **58**, *1,* May 8, 1978, 27-38.

For situations in which several modes may be contributing to a single resonance of a structure, a method for detecting the individual modes and for extracting useful information from the measurements is given. In addition, it is shown that noncrossing of the experimental nodal curves may occur when modal resonant responses overlap because of finite damping, and, for this situation also, a method is presented that allows the extraction of useful results from measurements.

● **6.12-16** Adeli, H., Gere, J. M. and Weaver, Jr., W., **Algorithms for nonlinear structural dynamics,** *Journal of the Structural Division, ASCE,* **104**, *ST2,* Proc. Paper 13538, Feb. 1978, 263-280.

Several competitive numerical integration techniques for nonlinear dynamic analysis of structures by the finite element method are examined and compared for a plane stress problem. Both material and geometric nonlinearities are included in the finite element formulation. Three explicit methods are investigated: (1) the central difference predictor; (2) the two-cycle iteration with the trapezoidal rule; and (3) the fourth-order Runge-Kutta method. A nodewise solution technique is generated at any state in the analysis. Three implicit methods also are studied: the Newmark-Beta method, the Houbolt method, and Park's stiffly stable method. Among the three explicit methods, it is concluded that the central difference predictor is the best, whereas the performances of the other two methods are about equal. The three implicit approaches are nearly equal, but Park's stiffly stable method is better than the Newmark-Beta method, and Houbolt's procedure is rated third.

● **6.12-17** Dunder, V. and Ridlon, S., **Practical applications of finite element method,** *Journal of the Structural Division, ASCE,* **104**, *ST1,* Proc. Paper 13475, Jan. 1978, 9-21.

Suggestions and comments based on 10 yr of experience with users of finite element programs and the programs themselves are given. Also included are two examples that illustrate modeling problems and underline the user's responsibility for use of a program and adequate modeling. Many articles and books have dealt with the finite element theory or computational algorithms, but only a few have dealt with the practical aspects of discretization and modeling or the practical use of finite element programs for structural analysis. This paper presents guidelines relating to application of the finite element method.

● **6.12-18** Sharma, C. B., **Calculation of integrals involving characteristic beam functions,** *Journal of Sound and Vibration,* **56**, *4,* Feb. 22, 1978, 475-480.

An analytical procedure is presented for evaluating some important integrals involving characteristic beam functions. These integrals were encountered in the vibration analyses of constrained and unconstrained circular cylindrical shells. The procedure should be useful in many other problems where characteristic beam functions are involved and should enable complicated and time-consuming computerized calculation of numerical integration to be avoided.

● **6.12-19** Arora, J. S. and Haug, E. J., **Efficient hybrid methods of optimal structural design,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *EM3,* Proc. Paper 13853, June 1978, 663-680.

An analysis of direct (mathematical programming) and optimality criteria (indirect search) methods for structural optimization is presented. It is shown that both approaches require similar calculations in their numerical algorithms. It is concluded that efficient, general hybrid methods can be developed, exploiting common features of both direct

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and optimality criteria methods. A numerical example is solved to assess the potential of hybrid methods. Extensions of the hybrid methods to dynamic response problems are discussed.

● 6.12-20 Dokumaci, E., **Element spaces and their separation for determining bounds to eigenvalues in vibration problems,** *Journal of Sound and Vibration,* **59,** *4,* Aug. 22, 1978, 557-566.

This paper introduces the concept of convergent eigenvalue transformations and elaborates on its use with the finite element method for obtaining close upper and lower bounds to the eigenvalues of continuous systems in free vibration. It is shown that, when incorporated with the finite element concept, convergent eigenvalue transformations attain a unique form defining an infinite number of convergent elements whose totality is referred to as an element space. Criteria are derived for the determination of the elements which give upper and lower bounds to the eigenvalues, and their applicability is discussed with reference to some vibration problems of beams. The analysis presupposes the knowledge of a convergent element but creates useful possibilities such as the improvement of known bounds, generation of bounds that are opposite to the known bounds, and assessment of the prevalent error laws.

6.12-21 Schreyer, H. L., **A numerical method for predicting seismic-induced impact between subassemblies in LMFBR cores,** *Nuclear Engineering and Design,* **49,** *1-2,* July 1978, 69-78.

Structural problems that incorporate impact usually require small time steps for numerical integration and, consequently, solutions are very expensive. Since impact is one of the basic phenomena involved in any study of fast breeder reactor cores subjected to seismic disturbances, it is imperative that simplified models be introduced to make safety studies economically feasible. In this paper an approach is proposed whereby only the magnitude of each impulse and not the history of the impact force is determined for each impact. The consequence of the procedure is that the maximum time step is governed by system parameters and not by a detailed characteristic of the contact region such as an equivalent contact spring. The concepts are developed with the use of a single degree-of-freedom model and the approach is applied to a three-assembly model of a reactor core. To obtain a solution, it is shown that the proposed direct approach may result in computer time that is less by an order of magnitude than the time required by the more conventional contact spring and gap element method.

● 6.12-22 Engels, R. C. and Meirovitch, L., **Simulation of continuous systems by periodic structures,** *Journal of Applied Mechanics, ASME,* 45, 2, June 1978, 385-392.

Many continuous systems can be approximated by periodic structures, i.e., structures consisting of identical substructures connected to each other in an identical manner. An efficient algorithm for the response of periodic structures is adapted to the treatment of continuous systems. The method is capable of deriving the response of damped or undamped systems subject to harmonically distributed loads. The length of the substructure can be made small arbitrarily without increasing the computational effort. Furthermore, the number of degrees-of-freedom of the substructure can be reasonably large.

● 6.12-23 Hughes, T. J. R. and Liu, W. K., **Implicit-explicit finite elements in transient analysis: stability theory,** *Journal of Applied Mechanics, ASME,* **45,** *2,* June 1978, 371-374.

A stability analysis is carried out for a new family of implicit-explicit finite element algorithms. The analysis shows that unconditional stability may be achieved for the implicit finite elements and that the critical time step of the explicit elements governs for the system.

● 6.12-24 Hughes, T. J. R. and Liu, W. K., **Implicit-explicit finite elements in transient analysis: implementation and numerical examples,** *Journal of Applied Mechanics, ASME,* **45,** *2,* June 1978, 375-378.

Computer implementation aspects and numerical evaluation of a new family of implicit-explicit finite element, transient algorithms are presented. It is shown that the new methods are easily coded and may be introduced into many existing implicit finite element codes with only slight modification. Numerical tests confirm the theoretical stability and accuracy characteristics of the methods presented in a companion paper.

● 6.12-25 Hughes, T. J. R., Caughey, T. K. and Liu, W. K., **Finite-element methods for nonlinear elastodynamics which conserve energy,** *Journal of Applied Mechanics, ASME,* **45,** 2, June 1978, 366-370.

A modification of the trapezoidal rule is presented which results in physically appropriate energy growth characteristics for nonlinear transient analysis. Particularly when external forces are absent, energy conservation is attained for nonlinear elastodynamics, and unconditional stability is thereby automatically achieved. Implementation aspects and numerical examples in support of the theory are described.

● 6.12-26 Ha, K. H., Fazio, P. and Moselhi, O., **Orthotropic membrane for tall building analysis,** *Journal of the Structural Division, ASCE,* **104,** *ST9,* Sept. 1978, 1495-1505.

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A method for analyzing tall framed buildings, based on the concept of equivalent elastic membrane, is presented. The elastic properties of the membrane are evaluated, taking into account the effects of finite size joints and axial deformations in the columns. Floors are assumed to be rigid in plane. The equivalent membrane is analyzed using two-dimensional plane stress, specially orthotropic finite elements. The displacements thus obtained represent directly those of the actual structure, and the member forces are determined by integrating the corresponding stress components in the membrane. Two multistory multibay frames were analyzed, and the results show that a high degree of accuracy can be obtained with a significantly smaller number of unknowns than by the "exact" and other simplified methods. The present technique can be applied to the static and dynamic analysis of tubed structures, clad multistory frames, and shear wall and framed structures.

● **6.12-27** Ting, E. C., Hong Chen, S. J. and Yao, J. T. P., **System identification, damage assessment and reliability evaluation of structures,** *CE-STR-78-1,* School of Civil Engineering, Purdue Univ., West Lafayette, Indiana, Feb. 1978, 62.

This report reviews and summarizes the available literature on the methods of system identification in structural engineering, and discusses the possibility of combining techniques of system identification, damage assessment, and reliability evaluation into a rational procedure for practical implementation. The available literature concerning structural identification is summarized in tabular form. In addition, several recommended procedures for inspection and safety assessment are summarized. It is concluded that further development and improvement are possible and desirable.

● **6.12-28** Kosloff, D. and Frazier, G. A., **Treatment of hourglass patterns in low order finite element codes,** *International Journal for Numerical and Analytical Methods in Geomechanics,* 2, *1,* Jan.-Mar. 1978, 57-72.

Numerical codes which use a one-point quadrature integration rule to calculate stiffness matrices for the 2-dimensional quadrilateral element and the 3-dimensional hexahedral element produce matrices that are singular with respect to a number of displacement patterns other than the rigid body patterns. In this paper, an economical method is derived to remove this singularity which also produces accurate flexural response. For rectilinear element geometry, the method is equivalent to the incompatible model element of Wilson et al. For nonrectilinear element geometry, a slight modification of the scheme is required in order to assure that it passes the patch test. The method can also be used for finite difference codes which present similar difficulties.

● **6.12-29** Schreyer, H. L., **Consistent diagonal mass matrices and finite element equations for one-dimensional problems,** *International Journal for Numerical Methods in Engineering,* 12, *7,* 1978, 1171-1184.

The conventional dynamic variational approach and finite element base functions lead to nondiagonal consistent mass matrices which are inappropriate for use with an explicit time-integration scheme. In this study, it is shown that if orthogonal base functions are used with a mixed variational formulation, then consistent diagonal mass matrices and corresponding sets of spatially discretized field equations are obtained. Although the approach is general, the theory is illustrated by a detailed development for one set of base functions. Central difference time integration is incorporated for applications to one-dimensional wave propagation and to Euler-Bernoulli beams. Numerical examples are provided for elastic and elastic-plastic materials.

● **6.12-30** Laursen, M. E. and Gellert, M., **Some criteria for numerically integrated matrices and quadrature formulas for triangles,** *International Journal for Numerical Methods in Engineering,* 12, *1,* 1978, 67-76.

For a large class of finite element matrices integrated numerically rather than exactly, a definable number of sampling points is found to be sufficient for keeping their theoretical properties unchanged. A systematic criterion which limits the number of possible point configurations for numerical quadrature formulas on triangles is established, and some new high-order formulas are presented. Tables containing optimal formulas with respect to minimum number of sampling points and required degrees of accuracy are given. They are arranged to allow the selection of suitable quadrature formulas for finite element computer programming.

● **6.12-31** Rich, T. P., **Closed form elastic-plastic stiffness matrix for axisymmetric finite elements,** *International Journal for Numerical Methods in Engineering,* **12**, *1,* 1978, 59-65.

This paper presents the closed form equations for the stiffness terms in the elastic-plastic stiffness matrix for axisymmetric finite elements. The element considered is a triangular ring element characterized by linear displacement relationships and an averaged state of stress. The physical law is modelled by the incremental theory of plasticity, utilizing the Prandtl-Reuss flow rule and the von-Mises yield criterion. Stiffness terms computed by numerical integration are compared to those computed by the closed form equations. Significant errors in stiffness terms arising from numerical integration are observed for axisymmetric elements located near the line of axial symmetry as a result of the logarithmic nature of some of the stiffness terms.

● **6.12-32** Gupta, A. K., **A finite element for transition from a fine to a coarse grid,** *International Journal for Numerical Methods in Engineering,* **12,** *1,* 1978, 35–45.

A formulation of a transition element is presented. Such an element makes it possible to match one element with two elements side-by-side. The resulting finite element model is easier to construct and has fewer elements and degrees-of-freedom than any other alternative model constructed with a similar order of elements. A modified quadrature formula is used to numerically integrate discontinuous functions in the expression of the stiffness matrix. Numerical examples show the applicability of the element.

● **6.12-33** Trujillo, D. M., **Application of dynamic programming to the general inverse problem,** *International Journal for Numerical Methods in Engineering,* **12,** *4,* 1978, 613–624.

In the general inverse problem, measurements are made on some of the state variables and the objective is to find the forcing functions. This problem is a natural one for the dynamic programming method. The formulation and solution of the problem are presented in matrix form, along with examples of an inverse heat conduction problem and an inverse structural dynamics problem.

● **6.12-34** El-Amin, F. M. and Kasem, M. A., **Higher-order horizontally-curved beam finite element including warping for steel bridges,** *International Journal for Numerical Methods in Engineering,* 12, *1,* 1978, 159–167.

The flexural stiffness for a horizontally curved beam element is developed for nodal parameters by assuming a cubic displacement function for vertical deflection w and a seventh order polynomial function for the angle of twist β along the length of the curved beam. The element gives good accuracy with even coarse mesh for the analysis of horizontally curved steel beams with an open thin-walled bisymmetrical cross section. Warping restraint is considered in the derivation of the stiffness matrix. It has considerable influence on the behavior and design of steel bridges which are curved in plan. The results obtained from such a new element are compared with those given by a lower order finite element developed previously by one of the authors and with theoretical solutions for the particular problem.

● **6.12-35** Gobmann, E., Krings, W. and Waller, H., **On suitable formulations of the method of modal analysis for numerical calculations,** *International Journal for Numerical Methods in Engineering,* **12,** *5,* 1978, 795–808.

The method of modal analysis is used widely in the structural analysis of linear systems. After a short introduction this paper examines two step-by-step formulations for modal calculations. One of them is of more theoretical interest while the other is recommended for practical calculations for multidegree-of-freedom systems because it is efficient in computing time. The first is formulated for the whole system, the latter for each mode. A combination of the modal analysis method and the Laplace transformation is also established. The numerical calculation of the Laplace transformation is accomplished using the algorithm of the fast Fourier transformation. The advantages of the different formulations for numerical calculations are discussed.

● **6.12-36** Pao, Y. C., **Algorithms for direct-access Gaussian solution of structural stiffness matrix equation,** *International Journal for Numerical Methods in Engineering,* **12,** *5,* 1978, 751–764.

Based on direct-access programming, algorithms have been developed for the generation, and solution by Gaussian elimination, of the structural stiffness matrix equation resulting from application of the finite element method in engineering analyses. A large disk storage is used to store the rows of the stiffness matrix as directly accessible records. The developed algorithm BAND2R requires only $2N_b$ in-core words in implementing the Gaussian elimination where N_b is the semi-band width of the stiffness matrix. Algorithms BANDSQ and BDSQMX are presented which require N_b^2 in-core words but minimize the number of times the direct-access records must be retrieved and restored during the Gaussian elimination. BANDSQ has the direct-access feature in both the elimination and backward-substitution steps whereas BDSQMX has the direct-access feature only in the backward-substitution step of the Gaussian elimination. Example applications of the developed algorithms are given, and the computer core and time requirements for BAND2R, BANDSQ, and BDSQMX are compared to those for the conventional Gaussian elimination using sequential, in-core storages. Methods for reducing the semi-band width N_b of the structural stiffness matrix are also discussed.

● **6.12-37** Rossow, M. P. and Katz, I. N., **Hierarchal finite elements and precomputed arrays,** *International Journal for Numerical Methods in Engineering,* 12, *6,* 1978, 977–999.

Two-dimensional C^0 finite elements of arbitrary polynomial order are developed for a general functional which includes a least squares or potential energy functional as special cases. The elements are "hierarchal" in the sense that the nodal variables for polynomial order p constitute a subset of the nodal variables for order $p + 1$. It is shown that the elemental arrays for high polynomial order may be efficiently computed by using hierarchal elements together with precomputed arrays—i.e., arrays which are computed once, stored on a permanent file, and then re-used in all subsequent applications of the program. A number of example problems are solved. Comparisons are made of the

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relative efficiency of finite element convergence with mesh refinement (polynomial order held fixed) and with increasing polynomial order (mesh held fixed). The latter approach is found to be superior.

● **6.12-38** Derecho, A. T., Ghosh, S. K. and Fintel, M., **Input motions for use in seismic response analysis of structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-28, 1978, 211–218.

The stochastic nature of earthquake motions requires the consideration of a sufficient number of input motions to establish critical structural response to potential earthquakes. To minimize the number of input motions that need to be considered, an examination is made of the major parameters characterizing strong motions as these relate to relevant response quantities. The three major parameters are intensity, duration, and frequency content. Major emphasis is placed on the effects of the frequency characteristics of input motions on dynamic inelastic response. Accelerograms are classified into two broad categories and the conditions noted under which each type is likely to produce a critical response.

● **6.12-39** Lee, J. P. and Chokshi, N. C., **Modeling of shear wall structures for seismic analysis,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-29, 1978, 211–217.

In lumped-mass modeling of shear wall structures for seismic analysis, walls between floors are commonly represented by single sticks whose equivalent shear areas are calculated using the rigidity method. In this paper, the thin wall beam theory method (TWBT), which takes into account the intersecting effect of the perpendicular walls neglected in the rigidity method, is employed to calculate the equivalent properties for the stick model. Differences between these two methods in calculating shear force distributions are compared and discussed.

● **6.12-40** Adeli, H., **Solution techniques for dynamic structural analysis,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-02, 1978, 7–14.

Four solution techniques for linear dynamic analysis of structures modeled by finite elements are studied. These are the central difference predictor, direct linear extrapolation with the trapezoidal rule, two-cycle iteration with the trapezoidal rule, and the normal mode method. The accuracy, stability, and efficiency of the solution procedures are examined by comparing the results from a plane stress example problem.

● **6.12-41** Poceski, A., **Application of the mixed finite element method for solution of dynamic problems,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-20, 1978, 143–150.

Finite element methods can be applied successfully to the solution of dynamic problems. The mixed finite element method, which is considered in this paper, has some advantages over the other methods. The mixed method is particularly suitable for analysis of linear structures with variable thicknesses, plates, and shells. The fundamentals of the method are given, and the method is used to calculate free vibrations of girders and plates. The accuracy of the computed frequencies is good.

● **6.12-42** Nemtchinov, Ju. I., **Analysis of buildings as spatial systems on seismic actions by finite element method,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-19, 1978, 133–142.

● **6.12-43** Hall, W. J., Morgan, J. R. and Newmark, N. M., **Traveling seismic waves and structural response,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1235–1246.

Observations of earthquake damage indicate that buildings undergo rotational as well as translational motion, and that structures on large foundations respond to ground shaking with less intensity than do smaller structures. In 1969, Newmark developed a basis for determining torsional earthquake effects in symmetrical buildings, and, in 1970, Yamahara offered an explanation of observed reductions in translational response of buildings as compared with free-field behavior. More recently, the authors presented a numerical technique for computing reduced building response by averaging an acceleration record successively over a transit time.

The acceleration time history is treated as a traveling seismic (shear) wave, and resulting translational and rotational motions of the base are obtained by using an averaging procedure. In this paper, various combined responses are computed and compared, and the practical implications of the results obtained are discussed.

● **6.12-44** Bell, K., **DYNOGS—a computer program for dynamic analysis of off-shore gravity platforms: theoretical manual,** *STF71 A78009,* Foundation of Scientific and Industrial Research, Norwegian Inst. of Technology, Trondheim, 1978, 65.

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The computational model, including mathematical formulation and solution procedure, used in the DYNOGS computer code is described. DYNOGS may be used to determine the frequencies and corresponding mode shapes for an arbitrary number of the lowest modes of free vibration, the steady state response to an imposed harmonic loading (including quasi-static response), and the stochastic response to short-term sea states described by different wave spectra for a linear, three-dimensional structural model composed of straight beam elements. The organization of the program is described, and numerical examples demonstrating some of its features are included.

● **6.12-45** Leung, A. Y.-T., **An accurate method of dynamic condensation in structural analysis,** *International Journal for Numerical Methods in Engineering,* **12**, *11*, 1978, 1705-1715.

A new and efficient method of dynamic condensation is presented. It reduces the order of dynamic matrices without introducing further approximation by representing exactly the passive coordinates in terms of the active ones. The resulting frequency-dependent eigenvalue problem is solved by a combined technique of Sturm sequence and subspace iteration. Examples are given for a space frame and for a substructure problem. Results are compared to the complete solution.

● **6.12-46** Martins, R. A. F. and Owen, D. R. J., **Thin plate semiloof element for structural analysis—including stability and natural vibrations,** *International Journal for Numerical Methods in Engineering,* **12**, *11*, 1978, 1667-1676.

This paper presents a thin plate element formulated in a similar way as the general three-dimensional semiloof shell element. This plate version possesses only one-half the number of degrees-of-freedom of the shell element and has the advantage that the formulation of the strains and other terms is very much simplified. The element is first assessed in static situations and then its performance in the solution of eigenvalue problems is considered.

● **6.12-47** Babuska, I. and Rheinboldt, W. C., ***A-posteriori* error estimates for the finite element method,** *International Journal for Numerical Methods in Engineering,* **12**, *10*, 1978, 1597-1615.

Computable *a-posteriori* error estimates for finite element solutions are derived in an asymptotic form for $h \to 0$ where h measures the size of the elements. The approach is similar to the residual method but differs from it in the use of norms of negative Sobolev spaces corresponding to the given bilinear (energy) form. For clarity, the presentation is restricted to one-dimensional model problems. Specifically, source, eigenvalue, and parabolic problems are considered involving a linear, self-adjoint operator of the second order. Applications to more general one-dimensional problems are straightforward. The results also extend to higher space dimensions, but this involves additional considerations. The estimates can be used for a practical *a-posteriori* assessment of the accuracy of a computed finite element solution and the estimates provide a basis for the design of adaptive finite element solvers.

● **6.12-48** Torkamani, M. A. M. and Hart, G. C., **System identification: impulse response functions,** *Journal of the Engineering Mechanics Division, ASCE,* **104**, *EM5*, Proc. Paper 14071, Oct. 1978, 1147-1158.

An approach is presented for estimating the impulse response function of a multidegree-of-freedom structural system. The approach discretizes the time axis into contiguous time segments and estimates the structure's impulse response function for each time segment. The identification problem is formulated in the time domain and in matrix form which is solvable using math programming techniques. The solution is a global optimum because the problem is a convex programming problem.

● **6.12-49** Kukreti, A. R. and Feng, C. C., **Dynamic substructuring for alternating subsystems,** *Journal of the Engineering Mechanics Division, ASCE,* **104**, *EM5*, Proc. Paper 14059, Oct. 1978, 1113-1129.

A method of analysis is developed for determining transient responses of large structural systems subject to changes of structural components. A dynamic structural system is divided into two subsystems: the support that remains unaltered and is subject to external excitations, and the branch that is liable to change and on which external excitations may be acting. A distinctive feature of the method is the use of specified sets of generalized modal displacement functions or mode shapes for each subsystem. This enables incorporation of the modal properties of the alternative subsystem without having to re-establish the entire system modal properties in each new analysis. The method is applied to a 16-story building rigid frame model. The method gives transient response results comparable to the conventionally integrated system analysis. Approximations resulting from modal truncation are the same as for the component-mode substitution method.

● **6.12-50** Felippa, C. A. and Park, K. C., **Computational aspects of time integration procedures in structural dynamics—Part 1: implementation,** *Journal of Applied Mechanics, ASME,* **45**, *3*, Sept. 1978, 595-602.

A unified approach for the implementation of direct time integration procedures in structural dynamics is presented. Two key performance assessment factors are considered, namely, computational effort and error propagation. It is shown that these factors are strongly affected by details in the reduction of the second-order equations of motion to a system of first-order equations, and by the

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computational path followed at each time step. Part 1 is devoted primarily to the study of the organization of the computational process. Specific implementation forms derivable from the unified approach are studied in detail and rated accordingly. An analysis of the computational error propagation characteristics of these implementations is presented in Part 2.

● **6.12-51** Park, K. C. and Felippa, C. A., **Computational aspects of time integration procedures in structural dynamics—Part 2: error propagation,** *Journal of Applied Mechanics, ASME,* **45,** *3,* Sept. 1978, 603–611.

The propagation of computational error in the direct time integration of the equations of structural dynamics is investigated. Asymptotic error propagation equations corresponding to the computational paths presented in Part 1 are derived and verified by means of numerical experiments. It is shown that there exists an implementation form that achieves optimum error control when used in conjunction with single-derivative methods. No such form is found for two-derivative methods. A numerical beating phenomenon is observed for certain implementations of the average acceleration method and the trapezoidal rule. From an error propagation standpoint, this phenomenon is highly undesirable.

● **6.12-52** Spanos, P.-T. D. and Iwan, W. D., **On the existence and uniqueness of solutions generated by equivalent linearization,** *International Journal of Non-Linear Mechanics,* **13,** 2, 1978, 71–78.

The existence and uniqueness of approximate solutions generated by the method of equivalent linearization are considered. For the stationary analysis of systems with harmonic or Gaussian random excitation, it is shown that, even though the equivalent linear system may not be unique, a simple element-by-element substitute system exists. Furthermore, this system is at least as good as any other similarly defined substitute system.

● **6.12-53** Van Fossen, D. B., **FESAP—design program for static and dynamic structural analysis,** *Computers & Structures,* **9,** *4,* Oct. 1978, 371–376.

The structural analysis program, SAP, has been widely accepted and modified to perform a variety of structural analyses at many universities and government and industrial organizations. This paper documents the development of SAP into a user-oriented program for linear dynamic and static analysis of large complex structures, called FESAP (finite element structural analysis program). The paper also describes companion computer programs which constitute a total design system for thermo-structural analysis. The system includes mesh generation programs, a heat transfer program, the structural analysis program, batch and interactive graphic computer programs, and post-processors for the results of the heat transfer and structural analysis programs.

● **6.12-54** Noor, A. K. and Hartley, S. J., **Evaluation of element stiffness matrices on CDC STAR-100 computer,** *Computers & Structures,* **9,** 2, Aug. 1978, 151–161.

An algorithm is presented for the evaluation of the stiffness matrices of higher-order elements on the CDC STAR-100 computer. Discussion is focused on the organization of the computation and the mode of storage of the different arrays to take advantage of the STAR pipeline (streaming) capability. An assessment is made of the performance of the proposed algorithm for generating the stiffness matrices of two higher-order composite shallow shell and plate elements having 80 and 176 degrees-of-freedom. Also, estimates are given of the CPU times required to evaluate the stiffness coefficients of three-dimensional hexahedral elements using the proposed algorithm.

● **6.12-55** Gellert, M., **A new algorithm for integration of dynamic systems,** *Computers & Structures,* **9,** *4,* Oct. 1978, 401–408.

A high precision unconditionally stable algorithm for computation of linear dynamic structural systems is described. It shares with lower-order algorithms the advantageous property of preservation of a banded form by the amplification matrix. This preservation is a result of discretization in space. Therefore, in contrast to the known high-precision algorithms employing full matrices, less computer space and fewer operations are needed. The new algorithm is free of both artificial damping in the undamped case as well as artificial oscillation in the postcritical damping region. Local truncation error analysis is made and the rate of convergence is proved. Applications to problems allowing comparison with existing results are presented. Excellent agreement with exact solutions is achieved and engineering accuracy is attained with relatively few time steps.

● **6.12-56** Akiyoshi, T., **Compatible viscous boundary for discrete models,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM5,* Proc. Paper 14093, Oct. 1978, 1253–1266.

A numerical method for dynamic analysis of an infinite discrete model by compatibly replacing it with a finite discrete model has been developed. The proposed model consists of one-dimensional lumped masses, shear springs, and perfectly absorbing dashpots arranged at the boundaries. These compatible viscous boundaries are applicable to any type of wave within the cutoff frequency. Theoretical reflections at the hybrid viscous boundaries proposed by Lysmer are shown and compared with those at the compatible viscous boundaries. Sinusoidal and random vibrations of the finite models are considered. In the proposed compatible model, disturbances always travel in the same form independent of the number of masses; however, the hybrid viscous boundaries cause imperfect absorptions which depend on the wave length and the mesh spacing of the finite model.

● **6.12-57** Surana, K. S., **Lumped mass matrices with non-zero inertia for general shell and axisymmetric shell elements,** *International Journal for Numerical Methods in Engineering,* 12, *11,* 1978, 1635–1650.

A diagonal lumped-mass formulation with non-zero inertia terms is presented for Ahmad's general shell element. The effect of coordinate transformation on the mass matrix is demonstrated. Due to arbitrary coördinate transformation on the nodal variables, the diagonal lumped mass matrix becomes a banded matrix of half bandwidth three. It is shown that with approximations this matrix can be made diagonal without appreciably affecting the results. Numerical examples are presented to illustrate the accuracy of the formulation. A similar lumped mass matrix formulation is given for axisymmetric shell elements.

● **6.12-58** Cedolin, L. and Gallagher, R., **A frontal-based solver for frequency analysis,** *International Journal for Numerical Methods in Engineering,* 12, *11,* 1978, 1659–1666.

The finite element solution of dynamic analysis problems can be prohibitively expensive if all degrees-of-freedom needed for the structural stiffness formulation are carried over into the dynamic analysis process. For this reason, many programs for dynamic analysis exploit what has come to be known as Guyan or static condensation. An alternative approach, requiring less algebraic manipulation and extending the capacity of the popular frontal solution algorithm of Iron's to eigenvalue and eigenvector calculation, is presented in this paper.

The development presumes that the mass matrix of the structure to be analyzed is available in diagonal, or lumped, form. If the adopted computational approach first calculates mass matrices with off-diagonal terms, then procedures are available for the transformation of the mass matrix into a diagonal form. Moreover, it is presumed that the terms of the mass matrix will affect only a portion of the full set of the degrees-of-freedom of the complete structure. For example, in plate or shell vibration analysis, it is customary to neglect the rotary inertia, i.e., the masses associated with the angular displacements. The procedure described in this paper makes use of different aspects of the frontal solver to: (1) perform a condensation of the degrees-of-freedom with which no mass is associated, (2) conduct a determinant search of the reduced system of equations to calculate the eigenvalues, and (3) perform a final calculation for the complete eigenvectors. These steps are accomplished without alteration of the sequence of operations of the original frontal algorithm. A listing of the essential modifications to Iron's algorithm, as previously published, is given in an appendix.

● **6.12-59** Bostjancic, J. and Sheppard, P., **Treatment of the results of a dynamic model test according to two different model similarities,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-16, 1978, 127–134.

The results of a shaking table test of a model stone masonry building are interpreted using the theories of general and complete model similarity. With such double interpretation, a large amount of useful data can be obtained simply and economically.

6.12-60 Bathe, K. J. *et al.*, **Some computational capabilities for nonlinear finite element analysis,** *Nuclear Engineering and Design,* 46, *2,* Apr. 1978, 429–455.

The computational capabilities of the computer program ADINA for stress analysis of structures and continua are described. The program can be employed effectively for various linear and nonlinear static and dynamic finite element analyses. The solutions of some problems using ADINA are presented to indicate the solution capabilities of the program.

● **6.12-61** Goodwin, G. C. and Payne, R. L., **Dynamic system identification: experimental design and data analysis,** *Mathematics in Science and Engineering, Vol. 136,* Academic Press, New York, 1977, 301.

The book is devoted to the theory of mathematical model building, using experimental data. The contents are as follows: Introduction and Statistical Background, Linear Least Squares and Normal Theory, Maximum Likelihood Estimators, Models for Dynamic Systems, Estimation for Dynamic Systems, Experiment Design, and Recursive Algorithms. Five appendixes contain information on results from distribution theory, limit theorems, stochastic processes, Martingale convergence results, and mathematical results. References and a subject index are included.

● **6.12-62** Johnson, J. J., **MODSAP-a modified version of the program SAP IV for the static and dynamic response of linear and localized nonlinear structures,** GA-*A14405,* General Atomic Co., San Diego, California, Apr. 1977, 14.

The computer program MODSAP is an expanded and modified version of the program SAP IV originally developed at the Univ. of California, Berkeley. This paper outlines the expanded capabilities of MODSAP. The library

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of finite elements is expanded to include a general three-dimensional element, a nonlinear line element, and two elements to analyze axisymmetric structures subjected to asymmetric loadings. The dynamic analysis capability of MODSAP is expanded over SAP IV for both time history and response spectrum analysis. The time history analysis of localized nonlinear structures is also permitted.

● **6.12-63** Michel, A. N. and Miller, R. K., **Qualitative analysis of large scale dynamical systems,** *Mathematics in Science and Engineering, Vol. 134,* Academic Press, New York, 1977, 289.

Several important classes of equations that can be used in the modeling of a great variety of large-scale dynamic systems are considered. Specifically treated are systems that may be represented by ordinary differential equations, ordinary difference equations, stochastic differential equations, functional differential equations, Volterra integrodifferential equations, and certain classes of partial differential equations. Hybrid dynamic systems, which are appropriately modeled by a mixture of different types of equations, are also discussed. Qualitative aspects of large-scale dynamic systems that are considered include Liapunov stability (stability, asymptotic stability, exponential stability, instability, and complete instability), Lagrange stability (boundedness and ultimate boundedness of solutions), estimates of trajectory behavior and trajectory bounds, input-output properties of dynamic systems (input-output stability, i.e., boundedness and continuity of the input-output relations that characterize dynamic systems), and questions concerning the well-posedness of large scale dynamic systems.

To demonstrate the usefulness of the method of analysis advanced and to point to various advantages and disadvantages, several specific examples from diverse areas, such as problems from control theory, circuit theory, nuclear reactor dynamics, and economics are included. Frequency domain techniques are emphasized in several examples because of their importance in applications. Necessary background material on many topics is included, and numerous references for this background material are provided.

● **6.12-64** Yun, C.-B. and Shinozuka, M., **Identification of nonlinear structural systems,** *Technical Report No. NSF-ENG-76-12257-3,* Dept. of Civil Engineering and Engineering Mechanics, Columbia Univ., New York, June 1978, 41.

Methods of identification of nonlinear multidegree-of-freedom structural systems are studied and applied to the problem of identifying the hydrodynamic coefficient matrices which appear in the equations of motion of offshore structures. Analytical simulation studies are peformed on a two degree-of-freedom structural system on the basis of simulated data.

● **6.12-65** Shinozuka, M., Yun, C.-B. and Imai, H., **Identification of linear structural systems,** *Technical Report No. NSF-ENG-76-12257-2,* Dept. of Civil Engineering and Engineering Mechanics, Columbia Univ., New York, May 1978, 81.

Structural dynamic analysis seeks to define the external loads acting on a structure, to develop analytical models for a structure, and to evaluate structural response. If the external forces are given deterministically, and the parameters of the structural model in terms of the equation of motion are specified, the response can be evaluated with relative ease. However, often in actual problems the external forces are not defined deterministically, and the parameters cannot be specified a priori. Therefore, the methods of estimating unknown parameters based on observed records of the external random forces and the subsequent structural responses are of considerable interest to the structural engineer. This paper examines methods of parameter estimation based on the observed data of applied forces and responses of linear multidegree-of-freedom structural systems. Analytical simulation studies are performed on the basis of simulated data to check the accuracy of the estimation methods. Then these methods are used to identify the aerodynamic coefficient matrices that appear in the equations of motion of a two-dimensional model of a suspension bridge using the field measurement data.

● **6.12-66** Beck, J. L., **Determining models of structures from earthquake records,** *EERL 78-01,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, California, June 1978, 300.

The problem of determining linear models of structures from seismic response data is studied using ideas from the theory of system identification. The investigation employs a general formulation called the output-error approach, in which optimal estimates of the model parameters are obtained by minimizing a selected measure-of-fit between the responses of the structure and the model. The question of whether the parameters can be determined uniquely and reliably in this way is studied for a general class of linear structural models. Because earthquake records are normally available from only a small number of locations in a structure, and because of measurement noise, it is necessary in practice to estimate parameters of the dominant modes in the records rather than the stiffness and damping matrices.

Two output-error techniques are investigated. Tests of the first, an optimal filter method, show that its advantages are offset by weaknesses which make it unsatisfactory for application to seismic response. A new technique called the modal minimization method is developed to overcome these weaknesses. It is a reliable and efficient method for determining the optimal estimates of modal parameters for

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linear structural models. The modal minimization method is applied to two multistory buildings that experienced the 1971 San Fernando earthquake. New information is obtained concerning the properties of the higher modes of the taller building, and more reliable estimates of the properties of the fundamental modes of both structures are found. The time-varying character of the equivalent linear parameters is also studied for both buildings. It is shown for both buildings that the optimal, time-invariant, linear models with a small number of modes can reproduce the strong-motion records much better than has been supposed from previous work using less systematic techniques.

● **6.12-67** Petrovski, D. and Naumovski, N., **An improvement of digital calculation of response spectra,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-17, 1978, 123–128.

● **6.12-68** Chandrasekaran, A. R. and Paul, D. K., **Merits of sub-system approach in a nuclear power plant analysis,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 129, Nov. 1978, 1025–1032.

In this paper, a comparison is made of the relative displacements of the top of a raft of an internal system in a nuclear power plant containment building. The raft is analyzed for two cases, namely, as part of a complete system and as a subsystem resting on a raft. In the latter case, the raft motion has been obtained from an approximate model of a complete system. The periods of the subsystem appear to be a subset of the complete system. It is seen that the response results obtained from the subsystem model do not compare well with results of the complete system.

● **6.12-69** Sato, H., **A study on estimating the response spectrum in terms of the plural ground predominant periods** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 128, Nov. 1978, 1017–1024.

The simulation of a response spectrum from an artificial earthquake is proposed and used to analyze the response of a two-degree-of-freedom system and ground characteristics. It is shown that the response spectrum of the acceleration amplification factor has two peaks. When the interval between the two peaks increases, the height of the peak for the single ground predominant period increases. The comparison of the simulated spectrum to the spectrum of an El Centro record showed good agreement not only for the magnitude of the amplification factor, but for the shape of the spectrum.

The analysis can be extended to the behavior of a structural appendage system. The maximum of the response spectrum of the structural appendage system, which occurs when its natural period is equal to that of the primary structure, was much smaller for the El Centro earthquake than for the simulated spectrum with a single ground predominant period. A decrease of the amplification factor of the primary structural system due to the existence of plural predominant period components in earthquake motion effectively reduces the amplification factor of the structural appendage system. Surprisingly good agreement of the simulated spectrum for two ground predominant periods with the spectrum for El Centro is obtained for the magnitude of the amplification factor and the shape of the spectrum. It is shown in the analysis that the amplification factor of the appendage to the primary structure is the same for both the simulation and El Centro as when the system has a shorter natural period that is apt to satisfy stationarity even in an actual earthquake motion.

It is verified that the simulation of the spectrum based on assuming two ground predominant periods explains well the characteristics of the earthquake motion. However, it was not possible to extend the analysis to the system to more than three dominant periods because of the complexity of the computation. A simple new method for estimating a response spectrum is developed to overcome this deficiency. The effect of the predominant periods overlapped when the square root of the sum of squares method was used. The rate merging the second or third predominant period is given by referring to the spectrum of the earthquake motion. It is shown that the spectrum for El Centro can be estimated by the simple method for magnitude and shape based on the fundamental spectrum for the single predominant period. It is also shown that the method is applicable to both a primary structure and a structural appendage system.

● **6.12-70** Sakurai, A. *et al.*, **Earthquake response analysis for multi-input systems by response spectrum method** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 126, Nov. 1978, 1001–1008.

The theory and applications of the earthquake response analysis of multi-input systems by means of the response spectrum method are presented. Multi-input systems, such as pipelines and piping systems in nuclear power plants, suffer different effects at each support during earthquakes. Different inertia forces and displacements must be considered at each support. The analysis can be calculated by a step-by-step integration procedure, but the computational difficulties prevent designers from using this procedure. The proposed method is an extension of the response spectrum method for single-input systems.

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The basic relation is shown in the form of a coefficient. The coefficient contains the influence of each mode of vibration and the influence of the input contribution of a support to the structural response whereas the corresponding coefficient of single-input systems contains only the effect of each mode. Based on the method, the earthquake response analysis can be easily completed following the same procedure for single-input systems.

In order to examine the applicability of the method, numerical and experimental research was conducted. The conclusions of the research are as follows: (1) For the superposition of each mode, the root mean square method is adopted. (2) For the superposition of response resulting from each input, the sum of the absolute value is adopted. (3) In the case of an input correlation, the response given by the method is overestimated as a rule. (4) The effect of phase lag of surface waves or traveling input was examined. In the case of few phase lags or high correlation, response by the method is in good agreement with results by the step-by-step integration procedure. When the phase lag increases, the difference between the method and the step-by-step integration increases and tends to converge to a value which is determined by independent input analysis. (5) The adaptability of the method to the earthquake response analysis of piping systems in nuclear power plants was examined. The results correspond to the case of high correlation, and the proposed method gives good results. (6) In general, response by a uniform input gives a maximum response. An easy way to analyze multi-input systems is to use the envelope response spectrum of each input.

● **6.12-71** Shibata, A. and Mizuno, J., **A simplified method for the evaluation of inelastic earthquake response of reinforced concrete frames,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 158, Nov. 1978, 1257–1264.

Presented is a method for evaluating the inelastic response properties of reinforced concrete structures subjected to random ground motion. The method utilizes an equivalent linearization method. A first-order differential equation governing the time variation of mean square response to nonstationary random ground motion is derived. The results from the proposed analytical method are in good agreement with those from time domain response simulation.

● **6.12-72** Mochizuki, T. *et al.,* **The earthquake response of power functional hysteretic systems by equivalent linearization method** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 148, Nov. 1978, 1177–1184.

This paper concerns the earthquake response of power functional hysteretic systems by means of the equivalent linearization method. Four methods are used to obtain an equivalent linear system for a power functional hysteretic system. The methods are the average stiffness and energy method, the average frequency and energy method, the harmonic equivalent linearization method, and the plastic flow method. Numerical results using these four systems are presented. The responses of four types of structures are studied. The structures are subjected to four earthquake waves with four levels. The numerical results are tabulated as maximum response values, and the average errors for the four equivalent linear systems are shown. Based on the results of this investigation, it is concluded that the harmonic equivalent linearization method is a useful tool in estimating the peak earthquake response of power functional hysteretic systems.

● **6.12-73** Braga, F. and Parducci, A., **Elastoplastic response spectra of the Friuli earthquakes. Effects of the decay of the mechanical properties in R/C structures taking into account the P-Δ effect,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. III, 583–604. (For a full bibliographic citation, see Abstract No. 1.2-7.)

The response spectra of elastoplastic oscillators are calculated for some of the principal records of the Friuli earthquakes. The P-Δ effect is considered and a decay mechanism of the mechanical properties that can reproduce the behavior of reinforced concrete structures during large seismic oscillations is taken into account. The results for different types of framed structures are reported. The conditions are described under which the combined effects of gravity and decay cause total structural collapse.

● **6.12-74** Suzuki, K. and Aoki, S., **Uncertainty analysis of seismic response of mechanical appendage system,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 37–44.

This paper discusses the uncertainty analysis of the maximum response properties of secondary appendage systems, such as piping and other mechanical equipment, in nuclear power plants and other industrial facilities. A simplified coupled supporting appendage model is introduced in this analysis. Nineteen representative records of strong earthquakes are used for the input ground acceleration. Attention is focused on the response characteristics of the appendage in the worst condition when the natural period of the supporting structure coincides with that of the appendage. By this means, the least feasible response of the appendage system is obtained.

Response properties are represented by a proposed floor response amplification factor (FRAF) which is obtained from the T_s-T_a envelope response spectrum and an ordinary response spectrum for a one-mass building model. The uncertainty of the FRAFs is investigated by calculating the expected value and the coefficient of variance. Through comparison of the results with those from the T_s-T_a envelope spectrum, it is shown that fluctuation of the FRAF becomes much smaller than that of the T_s-T_a envelope spectrum.

● 6.12-75 Sato, H., **A proposal for improvement estimating the response spectrum,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 45–52.

A method is proposed for simulating spectra which is based on statistically computed spectra and assumes a single ground predominant period. The method adopts the principle of the square root of the sum of the squares to calculate the effect of ground predominant periods. The procedure is simpler than statistical computation. The method is applied to both single and multidegree-of-freedom structures and their appendages. It is shown that the spectra estimated for these structures by the proposed method agrees well with earthquake motion in both magnitude and shape.

● 6.12-76 Van Pelt, J. M., **An automated desk method for analyzing load bearing masonry structures,** *North American Masonry Conference Proceedings,* Paper No. 88, 19. (For a full bibliographic citation, see Abstract 1.2-12.)

The analysis of load-bearing masonry structures involves complex and time-consuming engineering calculations. This paper discusses a preliminary automated method of analysis that can be performed on an inexpensive programmable printing desk calculator to obtain results in final publication form. The overall approach is discussed and individual programs which have been developed are assessed. The current capability of the analysis tool is reviewed and comments are solicited from experienced masonry structural engineers for incorporation into the final method.

● 6.12-77 Kaya, I. and McNiven, H. D., **Investigation of the elastic characteristics of a three story steel frame using system identification,** *UCB/EERC-78/24,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1978, 116. (NTIS Accession No. PB 296 225)

In this report, three different models in increasing order of complexity are used to identify the seismic behavior of a three-story steel frame subjected to arbitrary forcing functions, all of which excite responses within the elastic range. In the first model, five parameters have been used to identify the frame. Treating the system as a shear building, one stiffness coefficient is assigned to each floor and Rayleigh-type damping is introduced with two additional parameters. The mass, assumed to be concentrated at a floor level, is kept constant throughout the study. The parameters are established using a modified Gauss-Newton algorithm. The match between measured and predicted quantities is satisfactory when these quantities are restricted to floor acceleration or displacement.

To remove the constraint imposed by assuming that the frame deforms as a shear building, a second model with eight parameters is introduced, allowing rotations of the joints as independent degrees-of-freedom. Six of the eight parameters are related to the stiffness characteristics of the structural members, while the remaining two are related to damping as before. An integral squared error function is used to evaluate the discrepancy between the response of the model and the structure when both are subjected to the same excitation. Different quantities, such as displacements, accelerations, rotations, etc., are used in different combinations to form the error function in an effort to determine the best set of measurements that need to be made to identify the structure properly. The final eight-parameter model is the last of three. The discoveries that were made between the first and the third models are significant.

The match between measured and predicted quantities for the final model is excellent. The set of parameters derived from the minimum squared error gives a model that shows very good correlation using information on the full duration of the pulse or only a portion of it. Also, the same correlation exists between the coefficients obtained from different excitations.

To explain the values of the parameters associated with the girders, an additional degree-of-freedom, namely the pitching motion of the shaking table, is considered. The stiffness of the symmetrical springs at the base of the table is introduced as a ninth parameter in the model. The match between measured and predicted response is slightly improved over the eight-parameter model. The value of the nine-parameter model is not primarily caused by this improvement, but because from it is gained physical insight into the values to which the parameters converge during optimization. Comparison of the quality of predictions from the eight- and nine-parameter models shows that higher-order models would further improve the quality of the model little if any.

● 6.12-78 Row, D. G. and Powell, G. H., **A substructure technique for nonlinear and dynamic analysis,** *UCB/EERC-78/15,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1978, 202. (NTIS Accession No. PB 288 077)

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In the last decade, the field of computerized structural analysis has grown exponentially. The substructure technique has gained in popularity for linear analysis because it provides a convenient means of partitioning complex structures into manageable units. Additionally, the technique offers flexibility in structural description, computational savings for the case of repeated substructures, and a manageable data structure. Substructuring techniques are also attractive for the nonlinear analysis of large structures. Here also the structural description and data checking are simplified, and substantial computational savings may be possible.

In this paper, a "building block" procedure for structural description is presented, which is a generalization of the standard finite element assembly. The relation of each actual substructure to the complete structure is mapped through a connectivity tree. This tree provides the basis for data management and implementation of a systematic analysis procedure. The technique is formulated for nonlinear static and dynamic step-by-step analysis. With most solution strategies, nonlinear static or dynamic analysis requires a large number of step-by-step linear analyses. For a structure assembled as a single unit, a complete reanalysis may be required at each step if the nonlinearities are localized. A major computational advantage of the substructure technique is that only those substructures which change in behavior need to be reanalyzed at each step. Procedures for the direct solution of linear algebraic equations are reviewed, and a Cholesky-based algorithm is presented which minimizes the computational effort at each step. The substructure technique is implemented for nonlinear static analysis. The flexibility and efficiency of the technique are illustrated by performing substructure and conventional analyses on example structures.

● **6.12-79** Riahi, A., Row, D. G. and Powell, G. H., **Three dimensional inelastic frame elements for the ANSR-I program,** *UCB/EERC-78/06,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1978, 75. (NTIS Accession No. PB 295 755)

This report describes two elements developed to allow inelastic three-dimensional building frames to be analyzed using the ANSR-I computer program. The first element is a beam-column which has two-dimensional stiffness and yield characteristics. This element may be located arbitrarily in a three-dimensional structure and is intended primarily for modeling beams. The second element is a beam-column which has three-dimensional stiffness and yield characteristics. This element can be used for modeling columns in which biaxial bending effects may be important and also for structures such as elevator shafts.

Both elements assume that inelastic behavior is concentrated in plastic hinges at the element ends. For the two-dimensional element, the plastic hinges are affected by moment in the principal bending plane only or by this moment interacting with axial force. For the three-dimensional element, the plastic hinges are affected by bending moments about both axes, axial force, and, if desired, torsional moment. Allowance has been made for rigid floor diaphragms by means of a "slaving" feature. This slaving feature has been incorporated into both elements at the element level because ANSR-I cannot account for slaving at the nodal level. Both elements also allow for rigid end zones and for initial element actions. The theoretical formulations are presented, and the element characteristics are described. User's guides for both elements are included, and an example analysis is described.

● **6.12-80** Lopez, O. A. and Chopra, A. K., **Studies of structural response to earthquake ground motion,** *UCB/EERC-78/07,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1978, 99. (NTIS Accession No. PB 282 790)

The response of linear elastic and nonlinear hysteretic systems having a single degree-of-freedom to recorded and simulated ground motions is studied. The objective is to evaluate whether the commonly used simulated motions are appropriate for predicting inelastic response of structures and 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 white noise process passed through a SDOF filter and multiplied by a temporal intensity function. 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 made. 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 the 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.

The response of idealized one-story structural systems to earthquake ground motion is computed with the objective of evaluating the effects of gravity loads and vertical ground motions. It is shown 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 deformations resulting from horizontal ground motion. However, simpler analysis without such

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deformation coupling, but with reduction of lateral yield strength resulting from gravity load, would generally be satisfactory for predicting the lateral response of the system. It is shown that 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. Lateral deformations are not influenced significantly by vertical ground motion; hence they may be determined from analysis of the response to horizontal ground motion only.

6.12-81 Alarcon, E., Brebbia, C. and Dominguez, J., **The boundary element method in elasticity,** *International Journal of Mechanical Sciences,* **20,** *9,* 1978, 625–639.

This paper describes the application of the boundary element method for elasticity problems and discusses basic weighted residual expressions. Boundary elements of different orders are presented together with numerical integration techniques. The relationships are presented for three-dimensional elasticity and are specialized to the two-dimensional case. Results are presented and discussed, especially in relation to finite elements and other domain-type techniques.

● 6.12-82 Brebbia, C. A., **The boundary element method for engineers,** John Wiley & Sons, New York, 1978, 189.

The boundary element method is a technique which offers advantages over domain-type solutions, such as finite elements and finite differences. The method requires smaller systems of equations and a reduction in data required to run a problem. In addition, the numerical accuracy of boundary elements is generally greater than that of domain-type solutions. These advantages are more marked in two- and three-dimensional problems. The method is also suited to problem solving with infinite domains, such as those frequently occurring in soil mechanics, hydraulics, stress analysis, etc., for which the classical domain methods are unsuitable.

The term "boundary elements" is used to indicate the method whereby the external surface of a domain is divided into a series of elements over which the functions under consideration can vary in different ways, in much the same manner as in finite elements. This capability is important since, in the past, integral equation-type formulations were generally restricted to constant sources assumed to be concentrated at a series of points on the external surface of the body.

This book presents the boundary element method in a simple fashion using computer programs written in FORTRAN to help the beginner understand the basic principles of the method. The applications of the method to potential problems and two-dimensional elasticity are discussed in detail, together with the way in which functions of different orders can be used to form the boundary elements on the external surface of the body.

● 6.12-83 Vujanovic, B., **Conservation laws of dynamical systems via D'Alembert's principle,** *International Journal of Non-Linear Mechanics,* **13,** *3,* 1978, 185–197.

A method is examined for finding the conserved quantities of nonconservative holonomic dynamic systems. In contrast to the classical Noetherian approach, which is based upon the variational principle of Hamilton, the starting point in this paper is based on the differential principle of D'Alembert which is equally valid for conservative and nonconservative systems. In the second part of the paper symmetry properties are employed as a vehicle for obtaining approximate solutions of linear and nonlinear dynamic systems.

● 6.12-84 Atanackovic, T. M., **On a stationarity principle for non-conservative dynamical systems,** *International Journal of Non-Linear Mechanics,* **13,** *3,* 1978, 139–143.

A stationarity principle for nonconservative, holonomic dynamic systems is formulated. The principle is based on the notion of the Gateaux directional derivative. Its relationship to the classical and variational principle with noncommutative variational rules is discussed.

● 6.12-85 Thurston, G. A., **Roots of lambda matrices,** *Journal of Applied Mechanics, ASME,* **45,** *4,* Dec. 1978, 859–863.

A numerical method is outlined for computing roots of determinants of lambda matrices. Convergence of the method is quadratic as long as the derivative of the determinant does not vanish at the root. When the derivative is zero, the method may still converge in special cases. Three examples of mechanics problems giving rise to lambda matrices are included.

● 6.12-86 Argyris, J. H. and Dunne, P. C., **On isochoric finite elements,** *ISD-Report 230,* Inst. fur Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Univ. of Stuttgart, Stuttgart, July 1977, 57.

This publication contains two papers: *Constant Strain Finite Elements for Isochoric Strain Fields* and *Improved Displacement Finite Elements for Incompressible Materials.*

● 6.12-87 Argyris, J. H., Johnsen, Th. L. and Mlejnek, H. P., **On the natural factor in nonlinear analysis,** *Report 242,* Inst. fur Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Univ. of Stuttgart, Stuttgart, June 1978, 37.

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The natural factor approach as formulated for the linear displacement method is extended to nonlinear analysis. It is shown that the sparse population of the matrix factor may be efficiently utilized in the decomposition technique. Furthermore, it is demonstrated that, in ill-conditioned cases, the method performs better numerically than the standard Cholesky approach.

● **6.12-88** Rutenberg, A., Hsu, T.-I. and Tso, W. K., **Response spectrum techniques for asymmetric buildings,** *Earthquake Engineering & Structural Dynamics,* **6,** *5,* Sept.-Oct. 1978, 427-435.

A method is proposed for calculating the effect of torsion on each lateral load-resisting element of asymmetrical buildings based on the response spectrum technique. The method consists of: (1) obtaining the modal shear and torque of the building by the response spectrum technique; (2) computing the total modal shear forces on each frame by resolving the modal shear and torque on the building according to the principles of structural mechanics (the shear on each frame resulting from the lateral load effect and the torsional effect are combined algebraically); (3) obtaining the total shear force on each frame by combining the total modal shears on that frame in a root sum square manner.

Since the proper phase relationship between the lateral load effect and torsional effect is accounted for on a modal basis, it is believed that the proposed method provides a more realistic load estimate on the frames than the conventional approach. An example of a simplified mono-symmetrical frame structure is chosen to illustrate the accuracy of the proposed scheme, by using dynamic time-history analysis as a standard for comparison.

6.12-89 Sato, H., Komazaki, M. and Ohori, M., **An extensive study of a simple method for estimating the response spectrum based on a simulated spectrum,** *Nuclear Engineering and Design,* **50,** *3,* Nov. 1978, 399-410. (Expanded version of Invited Paper K4/9 presented at the 4th International Conference on Structural Mechanics in Reactor Technology, San Francisco, Aug. 15-19, 1977.)

A simple method of simulating a response spectrum is proposed and developed. The response spectrum of a single-degree-of-freedom system generally shows multi-peaks at ground predominant periods. The simulated response spectrum of a building and a building-appendage structure system is considered to be a standard and is statistically computed using the theory of random vibration assuming an earthquake motion with a single ground predominant period. Based on the fact that the simulated response spectrum for two ground predominant periods fits well with the spectrum for the earthquake motion, it is proposed that the simulated response spectrum can also be given by an adequate summation of the standard spectrum, which is carried out by the method of the square root of the sum of the squares. This makes it possible to simulate the spectrum which generally has plural ground predominant periods. This is virtually impossible using the statistical computation. It is shown that the method is generally applicable to multidegree-of-freedom building systems and appendages. This means that if the average response spectrum for a single-degree-of-freedom at a site is given, the so-called floor response spectrum can be estimated from the standard spectrum.

● **6.12-90** Kawai, T. and Toi, Y., **Crush analysis of engineering structures,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 141-148.

A method of crush analysis for structural members is outlined. The method uses a family of new discrete elements recently developed by the author. These discrete models consist of rigid bodies with two types of springs which connect the elements to each other and are distributed over the boundary surfaces among the elements. Spatial movement of each element can be characterized by the displacement of the corresponding centroid, so that, in any structural analysis, the size of the stiffness matrices of these elements never exceeds (6 x 6). Using the standard incremental load procedure, dynamic collapse analysis of a beam and a plate subjected to transverse impact and crush analysis of a simple framed structure are demonstrated.

● **6.12-91** Collings, A. G. and Saunders, L. R., **Use of trigonometric interpolation for the analytical determination of the dynamic response of linear systems to arbitrary inputs,** *Engineering Structures,* **1,** *1,* Oct. 1978, 41-52.

Commonly the loadings associated with the dynamic excitation of structural systems are expressed in the form of discrete time series. By the use of trigonometric interpolation, these inputs may be transformed into continuous time functions. The dynamic response of a linear structural system when subjected to such inputs may be computed by model analysis techniques. These methods require the solution of a set of uncoupled second-order linear ordinary differential equations with constant coefficients. The trigonometric interpolation function is a finite series of sine and cosine terms and hence it becomes a straightforward matter to solve the set of uncoupled differential equations for the displacements. Solutions obtained in this manner are also seen to be continuous functions expressed as finite series in sines and cosines. The associated velocities and accelerations may be easily obtained by differentiation of these expressions. The method is also free from the errors inherent in step-by-step integration methods, and the errors in the numerical determination of Duhamel integrals. The derivation of the coefficients of the time-series inputs and

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of the final evaluation of the dynamic response are both executed by a simple recursive algorithm which is fast and accurate. Since the only errors occur in the initial expression of the input data as a finite series of elementary functions—and these errors can be made very small—the method is an alternative to existing procedures. The method is illustrated in this paper by the computation of the dynamic response of a skeletal space frame when subjected to earthquake ground motions.

● **6.12-92** Argyris, J. H., Doltsinis, J. St. and Willam, K. J., **New developments in the inelastic analysis of quasistatic and dynamic problems,** *Report 252,* Inst. fur Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Univ. of Stuttgart, Stuttgart, 1978, 64.

Computational aspects are examined for the numerical analysis of inelastic structures and continua. The tracing of quasistatic and dynamic motions is considered with particular emphasis placed on the interaction of nonlinear and transient problems. In the first part, explicit and implicit solution methods 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 with special attention to the kinematics of finite deformation problems.

● **6.12-93** Carver, M. B. and MacEwen, S. R., **Numerical analysis of a system described by implicitly-defined ordinary differential equations containing numerous discontinuities,** *Applied Mathematical Modelling,* **2**, *4*, Dec. 1978, 280-286.

Standard error-controlled variable step size algorithms break down or become extremely inefficient when used to integrate small systems of ordinary differential equations subject to discontinuous definition. An efficient technique is presented for use in conjunction with a standard integration algorithm when the differential equations contain arbitrary discontinuities. The effectiveness of this technique is illustrated in the analysis of a structural model comprising a large, implicitly defined, ordinary differential set which is subject to numerous discontinuities occurring at arbitrary intervals.

● **6.12-94** Knudson, W. C. and Kumar, G. V. S., **Explicit time integration operators for nonlinear structural dynamics,** *Report 250,* Inst. fur Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Univ. of Stuttgart, Stuttgart, Sept. 1978, 105.

Explicit temporal algorithms are advantageous for nonlinear structural dynamics problems because they require less computation time per time step and less storage than implicit algorithms. Of the explicit methods used, Newmark's ($\beta = 0$) method and the central difference method are similar. The stability and accuracy characteristics of these methods are well established. This paper examines two recent explicit methods, Fu's method and Trujillo's method (alternating direction explicit) for their stability and accuracy characteristics. The accuracy and computer time requirements of Newmark's ($\beta = 0$) algorithm and the higher order cubic Hermitian algorithm, both implemented within the LARSTRAN computer package, are compared. Comparisons with the alternating direction explicit method are also made.

● **6.12-95** Karadeniz, H., **Solution of the eigenvalue problem in structural engineering** (Yapi muhendisliginde eigendeger problemlerinin cozumu, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **6**, *21,* Apr. 1978, 17-27.

In this paper, an iterative solution of the structural eigenvalue problem is explained. The solution is especially attractive when the consistent mass matrix is used. First, the stiffness matrix is decomposed by means of Choleski's routine and the iteration proceeds as a static solution at each step. The solution is extended to include the hydrodynamic added mass effect on structural vibration. The iteration algorithms are presented and a numerical example is demonstrated.

● **6.12-96** **A directory of computer software applications: civil & structural engineering, 1970-January 1978,** National Technical Information Service, Springfield, Virginia, 1978, 222.

6.13 Nondeterministic Methods of Dynamic Analysis

● **6.13-1** Hsu, T.-I. and Bernard, M. C., **A random process for earthquake simulation,** *Earthquake Engineering and Structural Dynamics,* **6**, *4,* July-Aug. 1978, 347-362.

A nonstationary modulated random process, obtained as the product of a time envelope function and a stationary random function, is used to simulate earthquake acceleration. The parameters and the frequency distribution of the simulation process can be obtained from past earthquake records. This simple and realistic model is suggested for use as input in the seismic-resistant design of structures.

● **6.13-2** Veneziano, D., Grigoriu, M. and Cornell, C. A., **Vector-process models for system reliability,** *Journal of the Engineering Mechanics Division, ASCE,* **103**, *EM3,* Proc. Paper 12981, June 1977, 441-460.

The theoretical and practical viability of multivariate time-dependent failure rate analysis is considered when the reliability model involves crossings of Gaussian n-vector processes out of safe regions. While the mathematical

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approach is not novel, its potential for engineering application has not been explored significantly before. In this sense, a number of specific results—such as the mean failure rate of systems with piecewise linear failure boundary—are derived, which will ease the application to many cases of engineering interest. Multivariate crossing problems of the type examined here arise in the safety study of structural systems subjected to multivariate time-dependent input or with multimodal failure conditions. Two examples of time-dependent static and dynamic structural safety are studied: an RC column under moment and axial force and the joint safety of three separate stories in a building subjected to random support movement.

● 6.13-3 Roberts, J. B., **First passage time for oscillators with non-linear restoring forces,** *Journal of Sound and Vibration,* **56,** *1,* Jan. 8, 1978, 71–86.

The Markov property of the energy envelope of a randomly excited, lightly damped oscillator, with a nonlinear restoring force, is used as the basis of a numerical method for calculating the probability of first passage failure, $P(T)$, in an interval 0-T. By a suitable transformation, it is shown that the diffusion equation of the energy envelope can be cast into a form which is similar to the limiting equation of a random walk process. This enables a discrete random walk analog of the energy envelope to be formulated, which, when used in conjunction with an appropriate absorbing barrier, allows $P(T)$ to be computed for oscillators with arbitrary nonlinear damping and restoring forces. Results obtained by this method are compared with corresponding digital simulation estimates for a Duffing-type oscillator.

● 6.13-4 Youssef, N. A. N. and Popplewell, N., **A theory of the greatest maximum response of linear structures,** *Journal of Sound and Vibration,* **56,** *1,* Jan. 8, 1978, 21–33.

A general theory is developed to estimate the greatest maximum response of linear structures subjected to deterministic or random excitations. The analysis utilizes the prolate spheroidal wave functions and the uncertainty principle. Such a technique is useful in checking the results of different methods, which may involve tedious calculations, for finding the response spectra of impulsive loads without knowing the load shape. It is also useful in designing seismic structures. The applications are illustrated by simple vibrating oscillators exposed to short- or long-duration loads.

● 6.13-5 Iyengar, R. N. and Dash, P. K., **Study of the random vibration of nonlinear systems by the Gaussian closure technique,** *Journal of Applied Mechanics, ASME,* **45,** *2,* June 1978, 393–399.

A technique is developed to study the random vibration of nonlinear systems. The method is based on the assumption that the joint probability density function of the response variables and input variables is Gaussian. It is shown that this method is more general than the statistical linearization technique in that it can handle non-Gaussian excitations and amplitude-limited responses. As an example, a bilinear hysteretic system under white noise excitation is analyzed. The prediction of various response statistics by this technique is in good agreement with other available results.

● 6.13-6 Grossmayer, R., **A response-spectrum based probabilistic design method,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-25, 1978, 183–190.

Probabilistic methods offer many advantages in seismic-resistant design. However, in most codes, earthquake loading is defined in terms of response spectra. The paper shows how a probabilistic design method can start with a given response spectrum by the conversion of it into a spectral density. This procedure leads to a better superposition formula and to a better way of handling secondary systems.

● 6.13-7 Savy, J. and Shah, H. C., **Determination of seismic design parameters: a stochastic approach,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-26, 1978, 191–198.

A model of earthquakes is developed by assuming that any given seismic event can be represented by a series of small fault ruptures (patches) where the energy is released by a dislocation mechanism. The geometry of the fault and its source mechanism are recognized as stochastic variables. A simulation process provides the statistics of the spectral density of the motion at a site for a given fault rupture, and a nonstationary Poisson model of occurrences combines the effect of all the faults. Consistent-risk spectral density, response spectrum, RMS response spectrum, and time histories are then derived as seismic design parameters.

● 6.13-8 Casciati, F., Faravelli, L. and Gobetti, A., **Residual displacements for rigid-plastic structures subject to stochastic ground accelerations,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-05, 1978, 31–38.

This paper presents a method for estimating the reliability of single degree-of-freedom rigid-plastic structures subject to ground accelerations, varying in time according to the shapes of real accelerograms. The method is based on the filtered Poisson process theory. Structural safety is

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regarded as a permanent displacement accumulation problem. The structural response is investigated with two numerical procedures to derive the residual displacement at the end of each accelerogram. Finally, some considerations on the constitutive law are developed and analytical results presented.

● **6.13-9** Barbat, H., Barbat, E. and Scharf, F., **Response of elevated water tanks subjected to stochastic modeled earthquakes,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-61, 1978, 459–464.

The main purpose of the paper is to give a stochastic model of the Romanian earthquake of Mar. 4, 1977. A method is presented for computing the maximum expected response of elevated water tanks subjected to earthquakes modeled as stochastic processes. Both stationary and nonstationary stochastic models are included in the analysis. The maximum expected response is obtained by solving the first passage problem. A computer program is developed and comparative numerical results are given.

● **6.13-10** Roberts, J. B., **The energy envelope of a randomly excited non-linear oscillator,** *Journal of Sound and Vibration,* **60,** 2, Sept. 22, 1978, 177–185.

The exact differential equation for the energy envelope of a randomly excited nonlinear oscillator is approximated by a time-averaging procedure. The resulting equation shows that, if the damping is sufficiently light and the correlation time scale of the excitation process is sufficiently small, the energy envelope can be approximated as a one-dimensional Markov process, governed by an appropriate Fokker-Planck equation. The physical significance of the terms in this latter equation is emphasized.

● **6.13-11** Parkus, H., ed., **Random excitation of structures by earthquakes and atmospheric turbulence,** *International Centre for Mechanical Sciences, Courses and Lectures No. 225,* Springer-Verlag, New York, 1977, 307.

The following papers pertinent to earthquake engineering were presented at a series of courses held at Udine, Italy, in July 1976. None of the papers is abstracted in this volume of the *AJEE*: *Seismic safety assessment,* Vanmarcke, E. H.—*An approach to characterizing, modeling and analyzing earthquake excitation records,* Kozin, F.—*Aseismic reliability and first-passage failure,* Grossmayer, R.—*Applications of digital simulation of Gaussian random processes,* Shinozuka, M.

● **6.13-12** Penzien, J., **Statistical nature of earthquake ground motions and structural response,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 59–70. (For a full bibliographic citation see Abstract No. 1.2-3.)

The variable characteristics of strong earthquake ground motions are discussed to provide a basis for the selection of motions for design purposes. It is recommended that the effects of local soil conditions on the characteristics of free field surface ground motions be considered. Emphasis is placed on the selection of motions having statistical characteristics similar to those of past recorded motions. The variable nature of structural response is presented in order to assess expected damage levels and possible losses.

● **6.13-13** Binder, R., **Covariance analysis of the response of buildings to earthquake loading,** *Seismic Safety of Buildings, Internal Study Report No. 15,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Oct. 1977, 59.

Seismic design poses many difficulties to the structural engineer largely because of the many uncertainties involved. Three major sources of uncertainty are (1) the ground motion (intensity or maximum acceleration, strong-motion duration, and frequency content); (2) the structure (dynamic properties, resistances of the structural members, and the stress-strain relationship of the materials or members); and (3) the response of the building (model of the building and method of analysis).

This report deals primarily with the third source of uncertainty, the method of analysis. It is assumed that the ground motion parameters are known and a simplified model of the building (the shear-beam model) with deterministic structural properties is selected. For that case, a method is proposed that has some advantages over the well-known methods of time-history analysis, response spectrum, and random vibration. The proposed method is applied to structures starting with the simplest case (a single-story, elastic structure subjected to white noise support motion) and proceeding to more realistic and complicated cases (multidegree-of-freedom systems with bilinear hysteretic behavior subjected to nonwhite noise motion). Whenever possible the results are compared with those of other methods.

● **6.13-14** Minai, R. and Suzuki, Y., **Stochastic prediction of maximum structural response to earthquake excitations,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 125, Nov. 1978, 993–1000.

An approximate analytical method is presented for determining the stochastic properties of the maximum response of linear and nonlinear hysteretic systems subjected to nonstationary random earthquake excitation. The maximum value of displacement response during the excitation is the significant and simplest response measure representing both the structural and functional damage in the structure. The maximum response is defined as a

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continuous random process in time and is described in the form of an appropriate first-order quasi-linear differential equation. It is shown that the Fokker-Planck formulation of the problem is derived by describing the state variables and constructing a system in the form of first-order differential equations. By making certain simplifying assumptions of the joint probability density function, a set of differential equations for the statistical analysis of nonstationary responses, including the maximum response, is derived and solved numerically. The probability density and the cumulative probability distribution of the maximum response are then evaluated. Numerical examples are given for a typical bilinear hysteretic system including a linear system. Results of the approximate method are compared with results obtained by digital simulation.

● **6.13-15** Watanabe, T. and Izumi, M., **Stochastic response analysis of nonlinear structures with equivalent linear method,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 147, Nov. 1978, 1169–1176.

This paper presents a simple equivalent linear method. The nonlinear system is replaced by an equivalent linear system with ductility-dependent stiffness and damping. The response statistics of the equivalent linear system are based on random vibration theory and Poisson approximation both of which are used to obtain the linear responses under stationary excitation. The statistics of the maximum response are obtained by iteration. Numerical examples are given for single degree-of-freedom systems. The results compare satisfactorily with empirical and simulated results.

● **6.13-16** Ishimaru, S., **On an analytical method of stochastic seismic response of hysteretic structure,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 146, Nov. 1978, 1161–1168.

An analytical method is presented to evaluate the response of a system with hysteretic restoring force characteristics subjected to random excitations. The procedure is based on the Kolmogorov (Fokker-Planck) approach, the Markov vector method, and the characteristic function method. The reliability of the proposed analytical method is confirmed by comparison with Monte Carlo simulation results.

● **6.13-17** Asano, K. and Suzuki, S., **Effect of time-dependent spectra of random earthquake excitations on hysteretic structural response,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 142, Nov. 1978, 1129–1136.

A new analytical technique is presented for the assessment of the random response of a bilinear hysteretic system with a single degree-of-freedom. The technique is used to investigate the effect of time-dependent spectra on the nonlinear hysteretic response of a structure. The earthquake excitations considered are random processes. The nonstationarity and nonwhite spectral characteristics of the processes are prescribed by an energy envelope and a time-dependent predominant angular frequency function. Numerical computations are carried out using the root mean square values of the nonstationary relative displacement response of a structural system with bilinear hysteretic characteristics by considering or neglecting the time dependence of the power spectra of earthquake excitations. It is concluded that the time dependence of power spectra should not be ignored from a structural damage point of view.

● **6.13-18** Fujita, T., **Probabilistic analysis of response for nonlinear systems under nonstationary random excitation** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 143, Nov. 1978, 1137–1144.

This paper deals with an approximate method for the probabilistic analysis of nonlinear response under nonstationary random excitation. The excitation is a nonstationary Gaussian shot noise which is a simple model for earthquake ground accelerations. Responses of nonlinear systems subjected to the nonstationary noise are analyzed based on the Markov-vector approach. The time-dependent joint probability density of the response displacement and velocity obeys that of the unstable Fokker-Planck equation, where the diffusion term (the second-order partial differential term) has a time-varying coefficient. As an approximate solution of that equation, a distribution based on the Maxwell-Boltzmann distribution is proposed for the class of nonlinear systems with symmetrical restoring forces. This solution contains three unknown functions of time. The system of first-order ordinary differential equations for these unknown functions is derived by employing the method of weighted residuals (the method of moment). The unknown functions are determined by solving this system of differential equations. The method is applied to a nonlinear system with collision; the system is strongly nonlinear. The system consists of an oscillator and reflectors at both sides, and the oscillator collides with both reflectors during vibration. Various probabilistic properties of the response are determined, including the probability densities and the second moments of displacement and velocity, the probability density of impact velocity, and the average number of collisions per unit of time. Experiments were carried out to verify the analytical result, and good correlation between analytical and experimental results was obtained.

● **6.13-19** Matsushima, Y., **Random response of bilinear hysteretic oscillator,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 141, Nov. 1978, 1121-1128.

This paper concerns the analytical estimation of the probabilistic properties of the stationary random response for a single degree-of-freedom system with bilinear hysteresis when the system is subjected to Gaussian white noise excitation. This estimation has been successfully achieved under the consideration that the response of a bilinear hysteretic system, which corresponds to one of the typical restoring force characteristics of building structures, could be evaluated by the comparison of this system with one exhibiting equivalent Coulomb damping. The approximate solution for the latter system is obtained by referring to one of the exact solutions for the associated Fokker-Planck equation. The expressions thus obtained are examined by Monte Carlo simulation. It is found that the analytical solution of the root mean square response of the displacement coincides with the corresponding experimental solution with sufficient accuracy and that the theoretical root mean square plastic deformation is in good agreement with the simulated estimate, except when either the input intensity or the plastic stiffness ratio is close to zero. In addition, it is concluded that the theoretical values of the expected accumulated plastic deformation agree quite well with the simulated values over wide ranges of related parameters.

● **6.13-20** Ishimaru, S., **Stochastic seismic response of hysteretic structures (Part I: on a system with bilinear hysteretic characteristics)** (in Japanese), *Transactions of the Architectural Institute of Japan, 265,* Mar. 1978, 71-80.

This paper describes a method for analyzing a system with bilinear hysteretic restoring force characteristics. The results are verified by a numerical simulation based on 30 artificial accelerograms generated by Gato's method and good agreement is obtained.

● **6.13-21** Ishimaru, S., **Stochastic seismic response of hysteretic structures (Part III: on the hysteretic structures with the Kato-Akiyama model)** (in Japanese), *Transactions of the Architectural Institute of Japan, 271,* Sept. 1978, 27-36.

This paper describes a procedure for the response analysis of steel structures subjected to random excitation. The procedure is based on a combination of the Markov vector method and the characteristic function method. Shown is the selected hysteresis, in which the yield strength is related to the cumulative plastic deformation. A good agreement is found between the method and the responses of a single degree-of-freedom system subjected to white noise.

● **6.13-22** Ishimaru, S., **Stochastic seismic response of hysteretic structures (Part II: on a hysteretic structure with slip model or peak-oriented stiffness-degrading model)** (in Japanese), *Transactions of the Architectural Institute of Japan, 267,* May 1978, 49-59.

This paper describes a procedure for applying the Kolmogorov approach (the Fokker-Planck approach) to hysteretic structures with a slip model or a peak-oriented, stiffness-degrading model subjected to random excitation. The technique is based on the Markov vector method and the characteristic function method.

● **6.13-23** Spanos, P.-T. D., **Energy analysis of structural vibrations under modulated random excitation,** *Journal of Structural Mechanics,* **6,** *3,* 1978, 289-302.

A method for determining the probabilistic characteristics of the total energy of a lightly damped linear structure under random excitation is presented. The excitation is a stationary broad-band random process modulated by a general deterministic time envelope. A first-order stochastic differential equation governing approximately the total energy of the structure is derived, and the associated Fokker-Planck equation is used obtain closed-form solutions for the statistical moments of the energy. Examples of applications are given.

● **6.13-24** Dolinski, K., **Kinematic approach to reliability estimate of stochastically loaded plastic structures,** *Journal of Structural Mechanics,* **6,** *3,* 1978, 247-266.

A method is developed to evaluate the reliability and to predict the lifetime of rigid plastic structures when the dynamic loading is a stochastic function of time alone. The method uses the mode approximation assumption relative to the deformed shape of the structure and supposes high reliability of the structure against plastic collapse under static loading. Failure of the structure is understood to be the first crossing of the level of admissible displacements. The random displacement field is determined by numerical simulation limited to the generation of a two-dimensional random variable. The method is illustrated by means of an example of a simply supported plate uniformly subjected to a stochastically varying pressure. The influence of the statistical parameters of stochastic loading on the reliability and on the lifetime of the structure is discussed.

● **6.13-25** Kaul, M. K., **Stochastic characterization of earthquakes through their response spectrum,** *Earthquake Engineering & Structural Dynamics,* **6,** *5,* Sept.-Oct. 1978, 497-509.

If earthquakes are modeled by a stochastic process, it is possible to interpret the associated response spectrum in terms of the statistics of extreme values of oscillator response to the process. For a stationary earthquake model,

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this interpretation leads to a relationship between the power spectral density function of the process and the response spectrum. This relationship is examined in this paper and forms the basis for two methods of obtaining the power spectrum of the earthquake process from its response spectrum. One of these methods is approximate but leads to an explicit representation of the power spectral density function in terms of the response spectrum. The other method, which is exact, establishes an iterative method for the solution of the problem. An example problem is solved to illustrate the use of the two methods, and it is shown that, for small values of damping, the approximate derivation yields a fairly accurate solution.

● **6.13-26** Spanos, P.-T. D. and Iwan, W. D., **Computational aspects for random vibration analysis,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM6,* Proc. Paper 14226, Dec. 1978, 1403–1415.

Computational aspects of the eigenfunction associated with the envelope of the nonstationary random response of a lightly damped linear oscillator are examined. Analytical formulas are given which may be used for an easily mechanized numerical computation of the probability density function and the moments of the response envelope. Formulas are also given to facilitate the numerical determination, based on a perturbation-type approach, of the statistics of the response envelope of a broad class of nonlinear oscillators. A Duffing oscillator is used for examples of specific computational problems.

● **6.13-27** Grigoriu, M. and Turkstra, C., **Structural safety indices for repeated loads,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM4,* Proc. Paper 13929, Aug. 1978, 829–844.

Approximations for the distribution functions of the extremes in a number of repetitions of a random variable are developed based on the crossing approach. Results are obtained for independent repetitions and Gauss-Markov correlated sequences and processes. These approximations are combined with an approximate full-distribution structural safety index in a number of examples. It is shown that correlation between consecutive load realizations can often be ignored in safety analysis for many situations.

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7. Earthquake-Resistant Design and Construction and Hazard Reduction

7.1 General

● 7.1-1 Sandi, H., **Combinations of seismic and non-seismic loading,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-16, 1978, 117–123.

Combinations of seismic and aseismic loads, to be considered in design, are discussed. To derive rules for combining components along different directions, a seismic load is represented as a spatially random action. For an aseismic load, given forces and displacements are briefly discussed. The probabilities of various spatial distributions of aseismic loads are considered, in order to discuss their simultaneous occurrence with seismic loads. Rules concerning the combination of seismic intensities with various spatial distributions of aseismic loads are presented.

● 7.1-2 Bertero, V. V. and Mahin, S. A., **Need for a comprehensive approach in establishing design earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1145–1156.

A logical approach to the seismic-resistant design of structures is the use of comprehensive design. Difficulties encountered in this approach arise from uncertainties regarding details of the critical ground motion and the inherent sensitivity of the response of structural systems to variations in these details. Design earthquakes for serviceability, damageability (where structural and nonstructural damage is limited to economically accepted levels), and collapse limit states are discussed. When serviceability controls the design, the most facilitative and reliable approach of specifying design earthquakes is based on smoothed response spectra. The use and reliability of standard linear elastic design response spectra (LEDRS) are reviewed. When damageability or collapse controls the design, design earthquakes are often specified using inelastic design response spectra (IDRS) derived directly by modifying the LEDRS. The use of these IDRS are shown to be unreliable for certain cases, and another approach is suggested. The need for a comprehensive approach is stressed, and research needs are discussed.

● 7.1-3 Nechaev, V. A., **Seismic effect rate-setting on construction,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-40, 1978, 305–309.

● 7.1-4 Rasskazovsky, V. T. and Aliyev, I. Kh., **Universal formula of seismic response spectra,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-21, 1978, 151–158.

On the basis of previous investigations of seismic acceleration spectral densities, an analytical expression for the upper estimate of seismic response is derived. Taken into account are natural vibration periods of structures, damping intensity, and predominant periods of actual earthquakes. By using approximating functions, a reasonably simple formula is constructed. Depending upon the earthquake period range, universal and regional formulas and a formula for mean seismological conditions are proposed. A comparative analysis of the spectral coefficients of U.S.S.R., U.S., Mexican, and Rumanian building codes is given.

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An earthquake is regarded as a nonstationary random process characterized by a set of response spectra for undamped systems. Elements of the set are response spectra of single events reduced to a unit standard with the predominant period of the earthquake as a parameter. Exclusion of this parameter by a semi-empirical procedure leads to a formula for the response spectra envelope. A comparison with response spectra maxima of many accelerograms shows good agreement. For damped systems, an empirical formula is derived by averaging the corresponding data from many accelerograms.

● 7.1-5 Pate, M.-E., **Public policy in earthquake effects mitigation: earthquake engineering and earthquake prediction,** *Technical Report No. 30,* John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, May 1978, 390.

The primary objective of this study is to provide a cost-benefit analysis method which considers the uncertainty of two major ways to mitigate earthquake hazards: earthquake engineering and earthquake prediction. The first part presents a probabilistic method for evaluating seismic losses in a region. The method considers losses caused by secondary hazards such as the flooding of dams, landslides, and liquefaction. The second part evaluates building codes with varying design levels and thus varying costs and loss ratios. The third part evaluates an earthquake prediction system and its inherent uncertainty. For each part, estimations are made of the expected values of the direct costs and losses and of the subsequent loss of economic activity. The corresponding number of casualties is computed separately. The benefits are determined by comparing the losses and costs of the policies under consideration. A numerical example is given for the San Francisco Bay area. Presented are the costs and benefits associated with use of the provisions of the 1973 and 1976 versions of the Uniform Building Code and the results expected from an earthquake prediction system.

● 7.1-6 Vanmarcke, E. H., **Risk and decision in engineering for natural hazards protection,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 18-32. (For a full bibliographic citation see Abstract No. 1.2-3.)

The paper presents a framework of decision analysis within which many of the critical engineering decisions about natural hazards protection can be usefully viewed. The rational resolution of problems of design, surveillance, and rehabilitation of structures in the face of natural hazards requires an understanding of the delicate interplay of technical, economic, and social issues. The proposed approach attempts to put these issues into focus by organizing factual information about risks and monetary and non-monetary costs and losses. The paper introduces a quantitative measure of the effectiveness of measures to mitigate hazards and develops a procedure for evaluating the probable benefits of a hazard mitigation program.

● 7.1-7 Murotsu, Y. *et al.*, **Optimum design problems in reliability-based structural design,** *HOPE International JSME Symposium-Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 461-466.

Five types of optimum design problems in reliability-based structural design are treated in this paper. Problem one specifies the allowable failure probability and determines the optimum structure to minimize structural cost. Problem two determines the optimum structure to minimize the expected total cost, which consists of the structural cost and the expected loss caused by the failure of the structure. Problem three specifies the allowable expected total cost and determines the optimum structure to minimize the failure probability. Problem four specifies the allowable expected total cost and determines the optimum structure to minimize the structural cost. Problem five specifies the allowable structural cost and determines the optimum structure to minimize the failure probability. The relationship between the problems is discussed, and it is shown that problems two, three, four, and five are solved by reducing them to problem one. Design procedures for each problem are proposed, and an example is presented.

● 7.1-8 Peterson, R. *et al.*, Comps., **Bibliography on grouting,** *Misc. Paper C-78-8,* Technical Information Center and Concrete Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, June 1978, 329. (NTIS Accession No. AD/A-057 831)

This bibliography on grouting contains abstracts of various engineering and scientific publications on both portland cement and chemical grouts. The technical data cover subjects such as dams, bridges, buildings, machinery foundations, tunnels, sewers, shafts, silos, roadbeds, pavements, soils, rock bolts, and miscellaneous structures.

● 7.1-9 Green, K. W., **Seismic design,** *Research & Design,* I, *2,* Apr. 1978, 6-19.

This article is oriented towards architects and includes a list of the AIA (American Inst. of Architects) Research Corp.'s projects in seismic design research.

● 7.1-10 Krishna, J., **Concepts for evaluation of seismic design codes for buildings and civil engineering structures; evaluation of design criteria for dams in seismic regions,** *61,* Inst. of Earthquake Engineering and Engineering Seismology, Univ. of Skopje, Skopje, Yugoslavia, June 1978, 20.

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7.2 Building Codes

● 7.2-1 ACI Committee 349, **Proposed addition to: code requirements for nuclear safety related concrete structures (ACI 349-76)**, *Journal of the American Concrete Institute*, 75, 8, Title No. 75-35, Aug. 1978, 329–335.

The proposed addition is an appendix defining minimum requirements for the design of steel embedments used to transmit loads from attachments into the reinforced concrete structures governed by the code. Loads may be transmitted into the structure by tension, bearing, shear, friction, or any combination thereof. The design limits have been established using both analytical and test methods. The proposed addition to the commentary (see Abstract No. 7.2–2) provides background information for the provisions incorporated in this appendix.

● 7.2-2 ACI Committee 349, **Addition to commentary on code requirements for nuclear safety related concrete structures (ACI 349-76)**, *Journal of the American Concrete Institute*, 75, 8, Title No. 75-36, Aug. 1978, 336–347.

The commentary on Appendix A has been approved for publication as part of the 1978 Supplement to ACI 349-76. Appendix A on thermal considerations was published in the Feb. 1977 ACI Journal; and was incorporated in the 1977 Supplement to ACI 349-76. Appendix A presents minimum requirements for members subjected to time-dependent and position-dependent temperature variations occurring during normal operation and accident conditions. The commentary presents some of the considerations of the committee in developing the code requirement published in Appendix A (see Abstract No. 7.2–1). Appendix B defines minimum requirements for the design of steel embedments used to transmit loads from attachments into the reinforced concrete structures governed by the code. Loads may be transmitted into the structure by tension, bearing, shear, friction or any combination thereof. The design limits have been established using both analytical and test methods.

● 7.2-3 ACI Committee 531, **Commentary on building code requirements for concrete masonry structures**, *Journal of the American Concrete Institute*, 75, 9, Title No. 75-50, Sept. 1978, 460–498.

The commentary discusses some of the considerations of Committee 531 in developing the "Building Code Requirements for Concrete Masonry Structures." The code covers concrete masonry structures or portions of structures. References to the research data are also provided.

● 7.2-4 ACI Committee 307, **Proposed revisions to ACI 307-69: specification for the design and construction of reinforced concrete chimneys**, *Journal of the American Concrete Institute*, 75, 9, Title No. 75-44, Sept. 1978, 421–428.

This report lists proposed revisions to the current standard. If approved, they will be incorporated into the standard, and the resulting document will supersede ACI 307-69. The specification gives material, construction, and design requirements for reinforced concrete chimneys. The report recommends loadings for the design of reinforced concrete chimneys and methods for determining the resulting stresses in the concrete and reinforcement. Curve charts are included to aid in the rapid solution of the specified formulas. The method of analysis applies primarily to chimneys, but it can be used for other hollow circular cross sections, with or without openings, where the shell thickness is small in proportion to the diameter.

Formulas are recommended for (1) determining the temperature gradient through the concrete resulting from the difference in temperature of the gases inside the chimney and the surrounding atmosphere and (2) methods for determining vertical and circumferential stresses in the concrete and reinforcement caused by the temperature gradient through the concrete. Formulas for combining the stresses caused by dead and wind or earthquake loads with the stresses caused by temperature are included in the specification, along with recommended allowable stresses in the concrete and reinforcement for the various stress combinations.

The specification refers to the ACI "Building Code Requirements for Reinforced Concrete" (ACI 318) for applicable requirements with supplemental provisions for concrete chimneys. Construction requirements are generally in accordance with ACI 318; however, design assumptions are based on working strength rather than ultimate strength procedures.

● 7.2-5 ACI Committee 349, **Proposed addition to: commentary on code requirements for nuclear safety related concrete structures (ACI 349-76)**, *Journal of the American Concrete Institute*, 75, 2, Title No. 75-4, Feb. 1978, 41–48.

This commentary explains Appendix C of the code. This appendix presents special provisions for the design of structural elements subjected to time-dependent loads resulting from collision of masses (impact) and time-dependent loads not associated with the collision of solid masses (impulse).

● 7.2-6 ACI Committee 531, **Proposed ACI standard: building code reqirements for concrete masonry structures**, *Journal of the American Concrete Institute*, 75, 8, Title No. 75-42, Aug. 1978, 384–403.

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This code covers the design of concrete masonry structures. It may be incorporated verbatim or by reference in a general building code. The quality and testing of materials are covered by reference to the appropriate ASTM standard specifications. Among the subjects included 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.

● 7.2-7 Solomon, K. A., Okrent, D. and Rubin, M., **Earthquake ordinances for the City of Los Angeles: a brief case study**, *UCLA-ENG-7765*, Chemical, Nuclear, and Thermal Engineering Dept., Univ. of California, Los Angeles, Oct. 1977, 65.

Following the 1933 Long Beach, California, earthquake, major building code revisions were made that required a certain level of earthquake resistance in all new buildings. Since then, the code has been revised many times, with the current code requiring substantially different design and construction standards than were used in pre-1933 structures. The philosophy behind the code changes appears to be that the public is entitled to a "resonable degree of safety" from earthquake-induced injury, which apparently was not provided by the pre-1933 Los Angeles Building Code.

This paper presents some problems concerning the decision-making process for seismic building codes. In addition, the history of earthquakes in the Los Angeles area is briefly examined, recent proposed earthquake ordinances are identified, public sentiment regarding earthquake ordinances (as depicted in newspaper editorials) is discussed, and the earthquake risks for unimproved and improved pre-1933 structures are compared. A brief UCLA report on the situation, as perceived in April 1976, and a copy of a briefing given to Governor Brown by the U.S. Geological Survey in March 1976 are included in an appendix. It is noted that several years ago the City of Long Beach, California, went through an extensive public examination of the adequacy of the seismic design of its older buildings and arrived at a new set of requirements. The City of Los Angeles has not yet faced the problem fully or arrived at a decision.

● 7.2-8 Petrini, V., **Comparative seismic risk analysis of different buildings in the same site**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-25, 1978, 179-185.

In many codes, the lateral force coefficient also depends on the structural type. Previous papers have dealt with the problem of the optimum choice of the ratio between seismic coefficients in different sites of a country for a standard building. This paper studies the influence of different structural types on the optimum distribution of money available for seismic risk prevention. Possible consequences of this parameter on seismic codes are examined.

● 7.2-9 Bubnov, S., **New Yugoslav regulations for earthquake engineering**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 5-03, 1978, 17-24.

The philosophy of the Yugoslavian regulations on earthquake-resistant design and construction is given. Main principles of the present regulations issued in 1964 and of the new ones to be issued in 1979 are presented. The determination of seismic forces acting on structures is noted. The necessity for finding a reasonable balance between the quality of seismological data and the methods for analyzing structures are emphasized.

● 7.2-10 Muller, F. P. and Keintzel, E., **Approximate analysis of torsional effects in the new German seismic code DIN 4149**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-14, 1978, 101-108.

An approximate analysis of torsional effects resulting from seismic loads, included in the new German seismic code DIN 4149 (draft Dec. 1976), is presented. The method, developed at the Inst. fur Beton und Stahlbeton of Karlsruhe Univ., is to be applied to asymmetrical structures, having centers of mass and rigidity essentially constant from floor to floor throughout the height of the building. An expression is given for a supplementary imaginary eccentricity, taking into account translational and torsional vibration coupling.

● 7.2-11 Demir, H. and Bazyar, T., **The comparative study of the earthquake resistances regulation of European countries**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 5-02, 1978, 9-16.

● 7.2-12 Shah, H. C., Zsutty, T. C. and McCann, Jr., M. W., **The purpose and effects of earthquake codes**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 5-01, 1978, 1-8.

Earthquake codes are legally enforceable rules for the design and construction of new buildings and for the rehabilitation of existing older structures. An essential requirement of these rules is that they be applicable to all construction so that the entire public is protected. The

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rules must have universal applicability if future disasters are to be avoided. The development of effective codes has been impeded in the past by overly conservative reaction to large earthquakes and by various other social and economic factors. It is the purpose of this paper to define the essential features of a workable seismic code and to give a history of various seismic codes so that past mistakes and failures will not be repeated.

● **7.2-13** Yerlici, V., **Suggestions for local code provisions on seismic design of prestressed concrete structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 5-06, 1978, 41–45.

Although findings on the seismic behavior of prestressed concrete structures are not yet conclusive, designers would like guidelines to follow. Reviewing the findings of the last decade and screening the authoritative recommendations on the subject, this study suggests some general and specific provisions for local codes. These provisions should be used as a supplement to regular design procedures.

● **7.2-14** Duarte, R. T. and Ravara, A., **An assessment of design methods for earthquake resistant codes,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 5-05, 1978, 33–40.

The structural-safety basis for earthquake-resistant design provides a conceptual framework in which the merits of design methods can be discussed. The usual idealizations of earthquake actions are assessed in terms of how well the important features of earthquake ground motions are reproduced, the amount of work required to determine structural responses, and the availability of required facilities. The use of a Gaussian stochastic process as a basic ground motion model and the associated analytical and experimental structural analysis methods are strongly advocated.

● **7.2-15** Bayulke, N., **An evaluation of the seismic design requirements of the code for highway bridge construction** (Depremlerle ilgili hukumleri acisindan "yol kopruleri icin teknik sartname" uzerinde dusunceler, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 5, *18,* July 1977, 26–36.

Earthquake-resistant features of the "Highway Bridges Design Specifications," issued by the Turkish General Directorate of Highways, are examined. Some weak points in the specifications are suggested.

● **7.2-16** Kallaby, J. and Mitchell, W. W., **Guidelines for design of offshore structures for earthquake environment,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1459–1471.

The effects of the earthquake hazard on the siting of offshore platforms are examined. The nature of the earthquake loading and how it is applied to the structure are considered. The design philosophy underlying the API-RP2A provisions in the editions since 1976 is reviewed, and directions for future guidelines are discussed. The behavior of systems and components is considered with respect to providing ductility in a platform structure.

● **7.2-17** Serinken, S., **A decision table evaluation of the building type coefficient of the earthquake code** (Deprem yonetmeligi yapi tipi katsayisinin karar tablosu teknigi ile incelenmesi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 5, *18,* July 1977, 37–41.

Decision tables combine and present related information expressing complex decision logic in a way that is easy to visualize and follow. The "K-coefficient" of the Turkish Code for the design and construction of structures in seismic areas is discussed using decision tables.

● **7.2-18** ACI Committee 443, **Analysis and design of reinforced concrete bridge structures,** American Concrete Inst., Detroit, 1977, *116.*

Recommendations made by American Concrete Inst. (ACI) Committee 443 for analysis and design of reinforced concrete bridges are reported. The section on ultimate load analysis and strength design is patterned after ACI 318-71 and strength design criteria of both the Federal Highway Admin. and the American Assn. of State Highway and Transportation Officials. Among the subjects covered are inspection; specifications; materials; concrete quality; mixing and placing; formwork, embedded pipes, and construction joints; reinforcement details; analysis and design; strength and serviceability; flexural and axial loads; shear and torsion; development of reinforcement; slab systems; walls; footings; precasting structures; and fatigue of materials.

The quality and testing of materials used in construction are covered by reference to the appropriate AASHTO and ASTM standard specifications. Welding of reinforcement is covered by reference to the appropriate AWS standard.

7.2-19 Uzumeri, S. M., Otani, S. and Collins, M. P., **An overview of Canadian code requirements for earthquake resistant concrete buildings,** *Canadian Journal of Civil Engineering,* 5, 3, Sept. 1978, 427–441.

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The need for earthquake-resistant construction in Canada is reviewed and the development of the Canadian code provisions for seismic design loads is summarized. Canadian code provisions for detailing earthquake-resistant concrete buildings and the manner in which some of these provisions are applied are described. Specific Canadian problems that still need to be solved are stated in conclusion.

● **7.2-20** Applied Technology Council, **Tentative provisions for the development of seismic regulations for buildings,** *ATC 3-06, NBS SP-510,* U.S. National Bureau of Standards, Washington, D.C., June 1978, 505.

This document contains tentative seismic design provisions for use in the development of seismic code regulations for the design and construction of buildings. The provisions represent the result of a concerted effort by a multidisciplinary team of nationally recognized experts in earthquake engineering. Design professionals, researchers, Federal agency representatives, staffs from the model code organizations, and representatives from state and local governments from throughout the United States were involved. The provisions are comprehensive in nature and deal with earthquake-resistant design of the structural system, architectural and nonstructural elements, and mechanical-electrical systems in buildings. Both new and existing buildings are included. These provisions embody several new concepts which are significant departures from existing seismic design provisions. An extensive commentary documenting the basis for the provisions is included.

● **7.2-21** Aoyama, H., **Development of earthquake resistant design method employing ultimate capacity concept,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 164–177. (For a full bibliographic citation see Abstract No. 1.2-3.)

The concept of the earthquake load, recently proposed in Japan, is introduced and discussed. This concept provides a simple and practical means for post-design examination of the earthquake-resistant capability of structures by evaluating the ultimate lateral capacity and the potentially nonlinear response displacement. The evaluation is accomplished by use of a simplified dynamic analysis and a perfectly elastoplastic model. Use of an effective period is shown to be valuable in evaluating the nonlinear response displacement associated with reinforced-concrete-type hysteresis. A proposed modification to the earthquake load concept, incorporating the concepts of effective period and ductility class, is introduced as a possible fundamental scheme for a limit state earthquake-resistant design method.

● **7.2-22** Demir, H. and Bazyar, H., **A concise presentation of the European earthquake resistance regulations,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 106, Nov. 1978, 841–848.

Trends toward the unification of the codes of European countries and the coordination of research work are occurring. In this study, available earthquake-resistant regulations of European countries are classified and compared from the viewpoint of design methods. The results are given in a tabulated form for easy reference.

● **7.2-23** Holland, E. P., Chmn., ACI Committee 318, **Building code requirements for reinforced concrete,** *ACI Standard 318-77,* American Concrete Inst., Detroit, 1977, 102.

This code covers the proper design and construction of buildings of reinforced concrete. It is written so that it may be adopted by reference in a general building code, and earlier editions have been widely used in this manner. See Abstract No. 7.2-24 for a commentary on this code. Among the subjects covered are permits and drawings; inspection; specifications; materials; concrete quality; mixing and placing; formwork, embedded pipes, and construction joints; reinforcement details; analysis and design; strength and serviceability; flexural and axial loads; shear and torsion; development of reinforcement; slab systems; walls; footings; precast concrete; prestressed concrete; shells and folded plate members; strength evaluation of existing structures; special provisions for seismic design in Appendix A, and an alternate design method in Appendix B. The quality and testing of materials used in the construction are covered by reference to the appropriate standard specifications of the American Society for Testing and Materials. Welding of reinforcement is covered by reference to the appropriate standard of the American Welding Society.

● **7.2-24** Holland, E. P., Chmn., ACI Committee 318, **Commentary on building code requirements for reinforced concrete (ACI 318-77),** American Concrete Inst., Detroit, 1977, 132.

Because the 1977 ACI Building Code (see Abstract No. 7.2-23) is written as a legal document so that it may be adopted by reference in a general building code, it cannot present background details or suggestions for carrying out its requirements or intent. It is the function of this commentary to fill this need. The commentary discusses some of the considerations of the committee in developing the code with emphasis given to the explanation of new or revised provisions that may be unfamiliar to code users. References to much of the research data referred to in preparing the code are cited for the user desiring to study individual questions in greater detail. Other documents that provide suggestions for carrying out the requirements of the code are also cited.

● 7.2-25 Goers, R. W. & Assoc., **Cost impact analysis for the construction recommendations in the report titled "A methodology for seismic design and construction of single family dwellings,"** Applied Technology Council, Jan. 1977, 254.

The increased costs which would be imposed by following the seismic-resistant construction recommendations specified in the report *A Methodology for Seismic Design and Construction of Single Family Dwellings* are analyzed. Five basic designs, four wood-frame and one exterior masonry-walled house, and two alternate designs are examined. The wood-frame houses are one-story, two-story, split-level, and split-entry. A different exterior finish material was assigned to each model. The split-entry home, Model F, had the heaviest roofing and exterior and interior wall finish materials. The exterior masonry-walled house was one-story and similar in floor plan to the one-story wood-frame house. In the alternate designs, the large windows and sliding doors of the one- and two-story houses were made smaller, making the total of houses studied seven. Each house was designed for Seismic Zones 2 and 3 and for 15 psf, 25 psf, and 40 psf wind load. The impact of the report recommendations on construction cost was determined for each design, using the Los Angeles region as a base area for incremental cost determinations and assuming the differential in cost to be the difference between the requirements of the report and the requirements of the Conventional Construction Provisions and other applicable sections of the 1973 Uniform Building Code. The results of the cost impact analysis by model and type of horizontal load are specified in terms of dollars and the percentage increase in construction costs. It is shown that the impact on construction costs in seismic regions is nominal, ranging from approximately 0.2% to 1.4%. The impact on construction costs for high wind load designs was more uniform but greater than for seismic-resistant design.

Other conclusions include: (1) Reasonable seismic protection similar to that offered other construction in Seismic Zones 2 and 3 can be provided in residential structures for relatively minimal cost. Certain configurations of homes which presently utilize construction details prone to seismic damage are subject to higher cost impact than more standardized designs. (2) The report was intended primarily to deal with the damage caused by earthquakes. Although it is flexible enough to be useful in designing for high wind loads as well, the methodology presented for the determination of wind loads to lines of shear resistance is not as sophisticated as it should be to allow for optimum economy in design. (3) The assignment of the same shear values for exterior and interior wall finish materials for both wind and seismic loads is questioned. It is suggested that a higher value (and therefore a lower factor of safety) might be acceptable for these materials in conjunction with wind load designs. (4) Testing to determine the uniformity and validity of the results on which shear resisting values are based is suggested. In addition, it is concluded that testing to determine allowable values for combinations of exterior and interior finish materials would reduce the cost impact of the methodology and provide more realistic and economical designs for both types of lateral loads. (5) In designing these homes the report was tested and found practical for use in seismic areas. However, revisions to the methodology would be necessary to obtain the same effectiveness in high wind areas.

● 7.2-26 Dickey, W. L., **Masonry in building codes,** *North American Masonry Conference Proceedings,* Paper No. 31, 15. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper presents the historical background of the use of masonry and the development of building codes affecting its use. Seismic considerations and design methods are examined, and areas of confusion and/or contradiction in the codes are discussed. The need for reorganization of code provisions and for development of codes based on valid data is summarized.

● 7.2-27 Haseltine, B. A., **A design guide for reinforced and prestressed brickwork,** *North American Masonry Conference Proceedings,* Paper No. 30, 14. (For a full bibliographic citation, see Abstract 1.2-12.)

Reinforced brickwork has been used, although not widely, in the United Kingdom (U.K.) for many years. The design guidance that was available was very poor. The existing "Code of Practice" covers only the design of reinforced walls. It is written in terms of permissible stress. All U.K. codes are being revised into limit state terms. A group of engineers under the auspices of the British Ceramic Research Assn. have prepared a design guide for the use of prestressed and reinforced clay brickwork in limit state terms. This paper describes the design guide with particular reference to design principles, reinforced brickwork walls and columns axially loaded, reinforced brickwork to resist lateral loads, the design of walls and columns subjected to vertical and lateral loads, reinforced brickwork beams, prestressed brickwork and the detailing, materials, properties, and use of the material. The research conducted in order to write the guide is briefly described.

● 7.2-28 Pyle, D. T. and Weber, D. C., **A structural engineer's rationalization of the masonry building code,** *North American Masonry Conference Proceedings,* Paper No. 32, 7. (For a full bibliographic citation, see Abstract 1.2-12.)

The major building codes such as the Uniform Building Code present a number of inconsistencies in the determination of allowable stresses and material properties and in design procedures. These inconsistencies, coupled with the current state-of-the-art in masonry design, testing and construction, present serious obstacles to the structural engineer. This paper discusses some of the problems and inconsistencies that must be resolved by the structural engineer who designs with reinforced masonry. The design guidelines and philosophy of a major structural engineering firm are presented.

● 7.2-29 Froerer, D. D., **The benefits of high-strength masonry,** *North American Masonry Conference Proceedings,* Paper No. 92, 17. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper analyzes Chapter 24 of the 1976 edition of the Uniform Building Code (UBC) and compares the stresses allowed in the UBC for conventional hollow-unit masonry and the stresses recommended in ICBO research report No. 2730 for high-strength masonry. The benefits from using such high-strength masonry in building designs consist of space efficiency, economy, greater load capacity with less reinforcing steel/grout, and smaller bearing areas.

Allowable axial load plots for reinforced, hollow-unit masonry walls, ungrouted and solidly grouted, are given as a function of wall height for several thicknesses. Allowable axial column stresses are also presented in graphs as a function of reinforcing steel for selected slenderness ratios. Comparable data showing allowable vertical loads for unreinforced brick masonry walls and columns are similarly displayed. Flexural coefficients for balanced, tension-reinforced masonry rectangular beams are plotted as a function of ultimate compressive masonry strength. These data assume the allowable steel stress to be 20,000 psi. In addition, allowable flexural shear values are established for reinforced masonry beams when the unit shearing stress is less than that allowed for the masonry and also when shear reinforcement is required to resist all the shear. The allowable shear stress in walls varies and depends on the strength of the masonry and the height-length ratios. Long, low walls have higher allowables than short, high walls. Figures showing the interaction between line shear, height-length ratios for shear walls with shear reinforcement are given for several wall thicknesses. Bearing area requirements for reinforced masonry subjected to concentrated loads are presented graphically for two extremes of masonry strength. Values given for 4-in. thick walls are for units complying with ICBO research report No. 3118. It should also be noted that the preceding information is based upon the requirement of special inspection.

7.2-30 Dayeh, R. J., **Design loads in a period of transition,** *Civil Engineering Transactions,* **CE 20,** *1,* 1978, 17-20.

A number of anomalies in the loading provisions of some Australian structural design codes are discussed. They are shown to result from inconsistencies between the provisions of the codes and the characteristics of the loads and their combinations. A general model for loading equations based on the limit-state design philosophy is presented, and partial safety factors used in the model are explained.

● 7.2-31 Allardice, N. W. *et al.*, **Seismic design of ductile moment resisting reinforced concrete frames—Section D: foundations for ductile frames,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *2,* June 1978, 122-128.

The New Zealand code D1.1 NZS 4203 sets general requirements for foundations and requirements for the capacity design of foundations for ductile reinforced concrete frames. This paper, the result of deliberations of a discussion group of the New Zealand National Society for Earthquake Engineering, makes recommendations for determining design loads for foundation systems to support and stabilize ductile frame structures and to couple such structures to the foundation material. Only simple cases are described.

● 7.2-32 McKenzie, G. H. F., **The new draft concrete design code,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *3,* Sept. 1978, 181-183.

This paper describes the contents of a draft of the New Zealand Standard, DZ 3101: Parts 1 and 2. The draft was published in June 1978. Part 1 is the "Code of Practice for the Design of Concrete Structures," and Part 2 is a commentary on the code. The code covers the design of buildings, bridges, and other engineering structures. It also covers the design of prestressed and partially prestressed structures and includes requirements for earthquake-resistant design.

● 7.2-33 Hatrick, A. V., **Dams and earthquakes in New Zealand,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *2,* June 1978, 94-100.

Recently there has been increased interest in New Zealand in small hydroelectric facilities, many of which will include dams. Although there is no official New Zealand code for the design of dams, the practice of the Ministry of Works and Development influences the design of most dams in the country for reasons which are explained in this paper. The paper describes guidelines currently used by the Ministry for the design of dams against earthquakes. Some background information is given on seismicity, the history of design approaches, and the experience of dams in earthquakes in New Zealand. Reference is made to some general aspects of dam design which help to put the seismic-resistant guidelines in perspective.

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

● 7.2-34 Elms, D. G. and Silvester, D., **Cost effectiveness of code base shear requirements for reinforced concrete frame structures,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11**, 2, June 1978, 85-93.

The appropriateness of the overall base shear levels prescribed by the New Zealand Loadings Code NZS 4203:1976 is investigated for reinforced concrete frame buildings. Six-story structures were designed to different base shear levels, and total costs were computed. Total cost takes into account capital costs, averaged direct economic loss due to earthquakes, and indirect earthquake losses. Damage levels were obtained from computer time-history analyses. It is shown that the code base shear levels are of the right order of magnitude for reinforced concrete frame buildings, but that the total costs of such buildings are not affected by design base shear level. The increase in capital cost of a concrete frame building which meets earthquake design requirements is of the order of 4%.

● 7.2-35 Cohen, L. and Noll, R., **The economics of disaster defense: the case of building codes to resist seismic shock,** *Social Science Working Paper 130,* Div. of the Humanities and Social Sciences, California Inst. of Technology, Pasadena, Mar. 1977, 34.

This paper discusses the problem of applying economic analysis to the design of building codes in earthquake-prone areas. The design of seismic building codes is treated as a problem in investment planning. A simple theoretical model is developed of the choice of an optimal building code, given that differing codes imply differing cost increments for structures and provide differing degrees of protection from seismic effects. The relationship between the optimal building code and the quality of information about the likelihood that an earthquake will occur is examined. This analysis provides some insight into the likely effect of the development of techniques to predict earthquakes. Also examined are the rudimentary data that are available to determine the extent to which building codes might be said to be economically optimal. Since the benefits of codes include savings in human lives and injuries, no definitive judgment on codes is offered. Instead, the rough order of magnitude of these benefits that is consistent with the data is calculated.

● 7.2-36 Bayulke, N., **Seismic behavior of masonry structures** (Tugla yigma yapilarin depremlerdeki davranislari, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **6**, *22,* July 1978, 26-42.

The dynamic characteristics and behavior of brick masonry buildings in Turkey are investigated. The characteristics of multistory brick masonry structures are measured by a periodmeter before and after earthquakes. The earthquake resistant design code provisions for brick masonry structures in Turkey are given and the behavior of several brick masonry buildings during the Nov. 24, 1976, Caldiran and Mar. 26, 1977, Palu (eastern Turkey) earthquakes are compared with the code provisions. In these comparisons, the importance of bearing wall length/floor area ratio is stressed and its importance for earthquake resistance is stated.

● 7.2-37 Keune, R. V., **Assessment of current building regulatory methods as applied to the needs of historic preservation projects,** *NBS Special Publication 524,* Center for Building Technology, U.S. National Bureau of Standards, Washington, D.C., Oct. 1978, 87.

To meet contemporary health and safety requirements as defined by the building regulatory system, conflicts frequently occur with the needs of historic building preservation projects. This project: (1) identified, evaluated, and proposed historic preservation categorical definitions as applied to buildings; (2) developed performance objectives, requirements, criteria, and tests for each definition category; and (3) identified and assessed those current methods most commonly used by regulatory jurisdictions to mitigate adverse impacts on building preservation projects.

● 7.2-38 **Peruvian building code** (Reglamento Nacional de Construcciones, in Spanish), Peru, Ministerio de Vivienda y Construccion [Lima], Apr. 1977, 22.

7.3 Design and Construction of Buildings

7.3-1 Stafford Smith, B. and Riddington, J. R., **The design of masonry infilled steel frames for bracing structures,** *The Structural Engineer,* **56B**, *1,* Mar. 1978, 1-7.

A design method is developed for the use of masonry infilled steel frames as sway bracing. The method is based on theoretical work presented by the authors in an earlier paper. The method accounts for the possible failure of the infill by either diagonal tension, horizontal shear, or corner compression. Axial forces, bending, and shear in the frame are also considered. A method for making a conservative estimate of the drift is proposed. It is shown that the compressive failure of the infill is strongly influenced by the column-infill relative stiffness, whereas shear and diagonal tensile failures are governed by the length-to-height ratio of the infill. Multistory and multibay infilled frames are included in the design method.

● 7.3-2 Shepherd, R., **High earthquake risk buildings in New Zealand,** *Earthquake Engineering and Structural Dynamics,* **6**, *4,* July-Aug. 1978, 383-395.

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

Many buildings in seismically active areas were constructed prior to the development of earthquake-resistant design criteria. Although such buildings are typically at least 50 years old, they still constitute a large proportion of occupied domestic and commercial structures. Since these structures comprise greater hazards than more recent constructions, they are referred to as high earthquake risk buildings. This paper discusses the problems of identification, assessment, and alleviation of the deficiencies of such structures in New Zealand.

● 7.3-3 Anagnostopoulos, S. A., Haviland, R. W. and Biggs, J. M., **Use of inelastic spectra in aseismic design,** *Journal of the Structural Division, ASCE,* **104,** *ST1,* Proc. Paper 13487, Jan. 1978, 95–109.

Modal analysis with inelastic response spectra is often used to design multistory frames subjected to earthquake motions. To evaluate the effectiveness of this approach, three different frames were designed using smooth inelastic spectra derived according to the Newmark-Hall rules for ductility factors of two and four. These frames were analyzed by an inelastic dynamic analysis program for three different artificial motions generated to match the design spectra. It was found that this design procedure fails to reflect variation of yielding patterns or local concentration of inelastic action. Curvature ductility factors at several locations exceed significantly the design ductility level. Axial forces in exterior columns produced by inelastic response can be larger than what inelastic spectra modal analysis predicts, leading to reduced plastic moment capacities and increased ductility demands. It appears that spectral modification factors could be used for local ductility control.

● 7.3-4 Roeder, C. W. and Popov, E. P., **Eccentrically braced steel frames for earthquakes,** *Journal of the Structural Division, ASCE,* **104,** *ST3,* Proc. Paper 13619, Mar. 1978, 391–412.

A unique practical structural steel system that is advantageous for the seismic-resistant design of structures is described. The system employs diagonal bracing with large eccentricity between the brace-beam connection and the beam-column joint. The eccentricity provides a ductile fuse that yields in shear and prevents brace buckling. Static and dynamic analyses indicate that this system can perform well during earthquakes because it combines the stiffness of a braced frame with the excellent energy dissipation of a moment resisting frame. One-third-scale experiments show that the system behaves as predicted in the analyses, i.e., it dissipates large amounts of energy while maintaining a stiff structure.

● 7.3-5 Ellingwood, B. and Leyendecker, E. V., **Approaches for design against progressive collapse,** *Journal of the Structural Division, ASCE,* **104,** *ST3,* Proc. Paper 13610, Mar. 1978, 413–423.

A progressive collapse is a chain reaction failure which follows damage to a relatively small portion of a structure. Since progressive collapse constitutes an unacceptable hazard, procedures for its control should be included in building standards. Design strategies for reducing the risk of initial failure and for controlling the amount of damage that occurs are presented, and their advantages are compared. Design criteria are given for the reduced loads to be carried by a damaged structure.

● 7.3-6 Wang, P., Drenick, R. F. and Wang, W. Y. L., **Seismic assessment of high-rise buildings,** *Journal of the Engineering Mechanics Division, ASCE,* **104,** *EM2,* Proc. Paper 13691, Apr. 1978, 441–456.

A method is presented to assess the seismic resistance of a structure. The method is based on the idea of the critical excitation of the structure, i.e., an excitation that drives one structural design variable to a larger response peak than any other in a given set of credible excitations. Evidence is presented which shows that a method based on the idea can be developed which shows promise but that substantial modifications are necessary. The evidence consists of the results of analyses of four highrise buildings, three already built and one in the planning stage. The method leads to designs that are somewhat conservative, but that appear to be consistent with established engineering practice. Its application, therefore, seems most appealing for structures that require a high level of confidence in their survival and integrity during an earthquake.

● 7.3-7 ACI Committee 115, **Research in progress—1978,** *Journal of the American Concrete Institute,* **75,** *8,* Title No. 75-43, Aug. 1978, 404–413.

More than 200 research projects on concrete materials, structures, and construction in progress throughout the world are listed. Each entry gives the project title, principal investigator(s), organization, and country.

● 7.3-8 Sharan, S. K., Clyde, D. and Turcke, D., **Equivalent frame analysis improvements for slab design,** *Journal of the American Concrete Institute,* **75,** *2,* Title No. 75-6, Feb. 1978, 55–59.

An improved equivalent frame method is proposed. It is demonstrated analytically that the equivalent member stiffnesses depend primarily on whether the slab or the column is loaded. This conclusion is supported by both numerical and experimental evidence. For the column-loaded case, it was found that the column stiffness should be increased. This is contrary to the ACI 318-71 assumption of a reduced effective stiffness. Using the results of an

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

in-depth numerical analysis of numerous slab-column structures, the authors provide convenient design curves to obtain equivalent member stiffness directly. Comparative results are shown between the current ACI method, the proposed method, and the experimental results. The proposed method is found to produce results in close agreement with the experimental results.

● **7.3-9** Gupta, V. K. and Murthy, P. N., **Optimal design of uniform non-homogeneous vibrating beams,** *Journal of Sound and Vibration,* **59,** *4,* Aug. 22, 1978, 521-531.

The problem of the optimal design of uniform nonhomogeneous beams undergoing transverse vibrations is investigated. The optimal longitudinal modulus distribution is sought to produce the maximum value of the fundamental frequency for a beam of given mass and geometry. Governing equations are obtained by using an optimal control theory approach. Solutions are presented for hinged-hinged, free-clamped, clamped-clamped, and clamped-hinged end conditions.

● **7.3-10** Ersoy, U., Aktan, E. and Tankut, T., **Earthquake resistance of prestressed concrete structures** (Ongerilmeli beton yapilarin deprem dayanimi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **5,** *20,* Jan. 1978, 1-7.

Prestressed concrete structures are generally not adequate for seismic regions. However, some special precautions may improve the behavior and strength of such structures. The limited literature on the subject has been reviewed to classify the possible precautions to be taken in this respect. The present paper is a brief account of these efforts.

● **7.3-11** Toprakci, R. T., **Analysis of lateral loads in low-rise shear wall structures** (Perde duvarli alcak yapilarda yatay yuklerin analizi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **5,** *19,* Oct. 1977, 1-16.

Lateral loads on buildings are carried by different structural systems. In small buildings behaving as box systems, lateral loads are carried in proportion to the relative rigidity of the walls. In this paper, a method which gives satisfactory results for design purposes is presented for analyzing the box system action. A sample building is studied to show the merits of the method.

● **7.3-12** Paulay, T., **An application of capacity design philosophy to gravity load dominated ductile reinforced concrete frames,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *1,* Mar. 1978, 50-61.

Indiscriminate application of the capacity design philosophy can lead to unnecessary conservatism in the earthquake-resistant design of gravity load-dominated ductile reinforced concrete frames. Low-rise framed buildings are typical examples. The origin of excessive potential strength with respect to lateral loading is discussed, and proposals are made to establish an acceptable upper bound for lateral load-carrying capacity in such frames. A technique is presented by which the successive formation of potential plastic hinges, involving partial beam-sway mechanisms, can be conveniently accomplished. While the requirements for energy dissipation in beams are retained, it is postulated that at an acceptably high level of lateral loading the formation of story mechanisms, necessary to complete the frame sway mechanism, should be tolerable. Examples are given to illustrate the determination of design quantities for bending moments and shear and axial forces for both beams and columns.

● **7.3-13** Lai, S.-S. P., **On inelastic response spectra for aseismic design,** *Evaluation of Seismic Safety of Buildings, No. 12, R78-18,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, July 1978, 152.

Sets of duration-dependent artificial strong ground motions are used in this study to investigate the sources of variability in inelastic response spectra, namely, strong ground motion duration, ductility level, and viscous damping ratio. From time-history analysis, it is concluded that the Newmark inelastic response spectra for elastoplastic systems are unconservative for 5% damping and conservative for 2% damping. By comparing the inelastic response ratios, new inelastic response spectra are proposed for different ductility factors and damping ratios. Based upon simulation studies, semi-empirical modifications to an elastoplastic random vibration model are suggested. The resulting probabilistic predictions of the inelastic responses are quite compatible with those obtained by the time-history analysis.

Three steel moment-resisting frames are analyzed to assess the validity of the modal analysis-based inelastic frame design procedure. The results indicate that this design procedure yields better frame designs than those based upon the Newmark inelastic spectrum. However, the procedure results in a conservative design for interior columns and girders and an unconservative design for upper-story exterior columns. The results also indicate that the maximum story displacement, predicted directly by the SRSS modal analysis using the inelastic displacement response spectrum, is too conservative. The conservatism is more pronounced at top stories.

● **7.3-14** **Seismic design: cost impact on high-rise residential structures,** Severud-Gruzen-Turner, New York, Sept. 1977, 190. (NTIS Accession No. PB 278 352)

This research study examines the cost impact of providing increased seismic resistance for prototype highrise apartment buildings. Eleven U.S. cities were chosen as case

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studies. Structures were designed to meet local building codes and seismic requirements, if any, and were redesigned to meet the seismic criteria of the U.S. Dept. of Housing and Urban Development Minimum Property Standards for Multifamily Housing, 4910.1, and the 1973 Uniform Building Code. Also, the cost impact of the 1976 Uniform Building Code in two of the case-study cities was examined. The cost impact generally proved to be greatest for cities which use local code requirements rather than one of the national model codes. For cities whose local seismic requirements are not stringent, upgrading resulted in significant additional costs, up to $3.42 per sq ft.

● **7.3-15** Katen-Yartsev, A. S. *et al.*, **Design principles of the gravity seismic isolated structures for civil housing,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-24, 1978, 173–177.

Theoretical fundamentals for the gravity seismic isolation of structures equipped with ellipsoidal pivoting supports in combination with damping systems are reported. Standards of the seismic isolation are formulated. Methods for determination of the gravity system optimum parameters are given. Methods for estimating seismic loadings on structures with the seismic isolation, the design principles of damping systems, and the fundamentals of rational design for components of the seismic isolating and damping systems are described.

● **7.3-16** Haug, Jr., E. J. and Feng, T.-T., **Optimal design of dynamically loaded continuous structures,** *International Journal for Numerical Methods in Engineering,* **12,** 2, 1978, 299–317.

A computational algorithm is developed and applied to the optimization of beam and plate structures subject to transient dynamic response constraints. A continuous design formulation is retained, with the dynamic response governed by partial differential operator equations. Adjoint equations are employed for sensitivity analysis, and a function space gradient projection optimization approach is presented. Finite element analysis methods are applied for solution of the system dynamic and adjoint differential equations. Displacement constrained beam and plate minimum weight examples are solved with a variety of boundary conditions.

● **7.3-17** Rosman, R., **Resistance of shear walls slitted at their bottom,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-31, 1978, 227–234.

Starting from a variation of the shock-absorbing soft story concept, which is applied to designs of high-rise buildings in Yugoslavia, the behavior of shear walls slitted at the bottom is studied by using a simple mechanical model. A straightforward design procedure is described. It is found that the inclination of the upper unslitted part of the wall substantially increases the bottom-end moments of the columns. Moreover, the inclination of the upper part of the wall increases the lateral deflections and the fundamental period of the lateral vibrations.

● **7.3-18** Zelic, F., **Enabling of existing buildings to take up seismic forces,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-45, 1978, 335–342.

● **7.3-19** Oliveira, C. S. and Ravara, A., **Methodology for strengthen existing structures built without the required earthquake resistance,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-44, 1978, 327–334.

An evaluation of the existing seismic-resistant capacity and criteria for strengthening a large number of one-to-nine-story reinforced concrete framed apartment houses built without governmental authorization is made. Among the possible ways of strengthening the buildings, the reinforcement of beam-column connections with steel plates glued to the concrete was considered to be adequate. The two main sources of uncertainty related to the problem were determining the actual capacity of the buildings to withstand seismic loads and the degree of seismic motion probable during their lifetimes. A cost-benefit analysis is briefly presented.

● **7.3-20** Arioglu, E. *et al.*, **Aseismic design and construction of a precast concrete industrial center with some test results,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-46, 1978, 343–350.

The earthquake-resistant design of the main structural frame of a precast concrete industrial center in Istanbul with 2000 modules designed by the authors is the subject of this study. General information on the structure, the geometric dimensions of the frame, the geotechnical parameters of the soil, the strength characteristics of the materials of the structural system, and a seismic risk analysis of the region are given. The earthquake-resistant features of the building and the connection details are examined. The "acceptance test" results of the precast elements under vertical, and the frame under lateral, loads are summarized, and the performance of the structure during an earthquake is analyzed by determining the reserve energy of the system using a "collapse behavior" diagram generated from the test behavior of the frame.

● **7.3-21** Zhunusov, T. Zh., Matviets, N. L. and Rotghaus, B. A., **Analysis peculiarities of seismic effects on multistorey hotel in Alma-Ata,** *Sixth European Conference on*

Earthquake Engineering, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-47, 1978, 351–357.

● 7.3-22 Fajfar, P., Fischinger, M. and Rogac, R., **The additional cost of earthquake resistant shear wall structures**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-32, 1978, 235–242.

The influence of the level of design lateral forces on the cost of earthquake-resistant shear wall structures is investigated. A typical Yugoslavian building design is considered. The number of stories is varied, and structures with and without coupling beams are studied. The response spectrum design method, which meets the Yugoslavian code, is used. The total base shear coefficient to the additional reinforcement ratio is presented; thus, the results are independent of the code spectrum and code coefficients. The cost increase for such earthquake-resistant shear wall structures is quite low.

● 7.3-23 Jabua, J. A. *et al.*, **Some research and designing problems of earthquake resistance of large-panel buildings**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-34, 1978, 251–256.

● 7.3-24 Bertero, V. V. and Zagajeski, S. W., **Computer-aided seismic resistant design of R/C multistory frames**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-39, 1978, 289–296.

This paper summarizes a computer-aided procedure developed for designing reinforced concrete multistory frames that can withstand severe earthquake ground motions. The design procedure is divided into preliminary and final design phases. Both phases employ optimization using a linear programming technique and static and dynamic linear-elastic and nonlinear analysis procedures. Automated member design allows several preliminary designs to be obtained in a short time. The procedure, which is very versatile, was used to obtain alternative designs for a ten-story, three-bay reinforced concrete frame. These designs are compared to a design conforming to UBC seismic forces and code requirements.

● 7.3-25 Poceski, A., Spasov, A. and Simovski, V., **Non-stationary bilinear concept of earthquake resistant design**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-75, 1978, 561–568.

A non-stationary bilinear system for classical framed structures diagonally braced by cables which start action after reaching a certain predetermined deflection is discussed. The system is designed for increasing stiffness and has variable dynamic characteristics. The system is adaptable to external excitation, and, consequently, its response is lower than the response of the corresponding linear system. The decrease in response, when the system was subjected to the Parkfield 1966 st. 2 earthquake, is approximately three times.

● 7.3-26 Cakiroglu, A. and Ozmen, G., **A method of successive approximations for distributing lateral loads among structural walls**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-30, 1978, 219–226.

In this paper, a method for successively approximating lateral load distributions among structural walls and core units is developed. Distribution coefficients are determined by using compatibility conditions which are expressed in terms of slope differences at each floor level. The convergence speed of the method is fast; thus it is possible to find an accurate solution in the first few steps. The method is practical in the sense that it can also be applied locally; i.e., only to those regions where the wall bending rigidity ratios differ. Many special characteristics met in practical applications, such as elastic supports, walls with small openings, effect of shear deformations and second-order theory can be incorporated easily into the analysis.

● 7.3-27 Anderson, D. L., Nathan, N. D. and Cherry, S., **Seismic hazard evaluation of existing buildings**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 5-04, 1978, 25–32.

Attention is drawn to the problems surrounding buildings which were designed before current seismic design criteria were established. The recommendations of the Applied Technology Council in the U.S. are briefly outlined; they consist of a preliminary classification, a more rigorous analysis of borderline cases, and updating requirements for buildings judged to be inadequate. A form of analysis is proposed for buildings that defy simple classification. It is believed that the method is more rational than has hitherto been proposed and that it enables a reasoned judgement to be made on corrective measures.

● 7.3-28 Korenev, B. G. and Poliakov, V. S., **Reduction of seismic structural response using the vibration absorber**, *Sixth European Conference on Earthquake Engineering*, Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-22, 1978, 159–166.

The paper analyzes some problems in determining the efficiency of vibration absorbers employed to increase the seismic resistance of structures. The structures are designed as systems with one or several degrees-of-freedom. An example is given using accelerograms of the 1976 Gazlii, U.S.S.R., earthquake.

● 7.3-29 Mahin, S. A. and Bertero, V. V., **Reliability of inelastic design methods for seismic-resistant structures,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-03, 1978, 15-22.

This paper examines the reliability of two general design methods in which seismic forces for structures that can be allowed to yield are determined by modifying a linear elastic design response spectrum in terms of a specified ductility factor. The effect of different accelerograms as well as of structural damping and hysteretic characteristics on the inelastic response of single and multidegree-of-freedom systems designed using these methods is investigated considering maximum displacement ductilities, maximum and permanent drifts, hysteretic energy dissipation, etc. Results indicate that the methods considered do not reliably limit ductilities to specified values.

● 7.3-30 Koridze, A. Kh., Makhatadze, L. N. and Mukhadze, T. N., **On the earthquake resistance of curtain walls of rural industrial buildings,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-73, 1978, 549-551.

Data are given on the behavior of rural industrial buildings during strong earthquakes. On the basis of the analysis of damage to curtain walls, suggestions are made to improve wall design.

● 7.3-31 McCue, G. M., Skaff, A. and Boyce, J. W., **Architectural design of building components for earthquakes,** MBT Assoc., San Francisco, 1978, 236.

The dynamic principles governing site and building response are reviewed to provide a basis for a conceptual model of building and component interaction during earthquakes. This conceptual model consists of: (1) a four-part dynamic model, which describes the various elements of a building, their interactive relationships during earthquakes, and the effect of their interaction on overall building response; and (2) the dynamic environment, which describes the nature of the seismic motions that a component will be subjected to in a particular location of a building. Any given component will have its own particular dynamic environment.

The conceptual model is then applied to architectural design procedures. Two studies illustrate the design of building components according to the principles of the model. In a case study of an enclosure wall system, design objectives are defined and alternative design concepts are studied. The wall is designed to meet the given seismic design criteria. A study of selected ceiling and partition systems defines generic ceiling systems and partitions, discusses their possible responses to input motions, identifies potentially damaging responses, and suggests means of achieving compatibility between interacting systems.

● 7.3-32 Cochrane, H. C., **Potential for inflated building costs after disaster,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1511-1524.

Earth movement in the Palmdale vicinity has concerned public administrators both in California and in Washington, D.C. Legislation allocating funds for community preparedness and additional monitoring of the region's seismicity has increased. Why earthquake proofing techniques, land use management plans and other damage mitigating adjustments have not been more widely accepted has once again gained the attention of public officials. This theoretical paper assesses the benefits to be derived from these adjustments, but not only in terms of loss reduction. Under certain circumstances resulting from moderate and strong earthquakes, significant reconstruction bottlenecks and material shortages are likely. The paper presents a model of optimal adjustment to the earthquake hazard, recognizing that a potential for inflation of construction costs exists. The model formulated extends the work of Russell, and Howe and Cochrane. The results demonstrate that more stringent building codes and land use guidelines are economically justifiable if the inflationary costs to reconstruct and repair buildings designed according to existing codes are considered.

● 7.3-33 Cheng, F. Y. and Srifuengfung, D., **Optimum structural design for simultaneous multicomponent static and dynamic inputs,** *International Journal for Numerical Methods in Engineering,* 13, 2, 1978, 353-371.

The optimality criterion and recursion procedure method is employed for the design of braced and unbraced structural systems subjected to static and dynamic forces. The dynamic excitations can be applied forces, ground motions, or the equivalent seismic forces of the Uniform Building Code (UBC). By using a sophisticated computer program, it has been found that: (1) for a set of given loads and constraints, the optimum braced system is lighter than an unbraced system; (2) the use in the design of the natural period recommended by the UBC yields a lighter structure than that based on the period of the eigensolution; (3) for seismic structural design, three to five fundamental modes are needed for adequate accuracy, and the P-Δ effect, caused by vertical ground motion and the gravity load, must be considered because the effect demands heavier structural design; (4) the UBC does not provide an adequate structural design for an actual earthquake response spectrum; and (5) the interaction of three-dimensional earthquake motions can significantly influence an optimum design, and this interaction is currently under investigation.

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● 7.3-34 Seckin, M. and Uzumeri, S. M., **Examination of design criteria for beam-column joints,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-23, 1978, 183-190.

The paper examines the design criteria for beam-column joints proposed by the Joint ASCE-ACI Committee 352 based on the results of a current research program at the Univ. of Toronto. The research program consisted of reversed cyclic load tests of nine full-size specimens with 30.5 cm x 51 cm (12 in. x 20 in.) or 38 cm x 51 cm (15 in. x 20 in.) beams framing into 38 cm x 38 cm (15 in. x 15 in.) columns. To examine the effect of the magnitude of the axial load applied to the columns, the columns were subjected to axial compressive forces in the range of 0.09 P_o - 0.79 P_o. It was observed that the magnitude of the column axial load did not affect the strength of the specimens.

● 7.3-35 Liu, S.-C. and Yao, J. T. P., **Structural identification concept,** *Journal of the Structural Division, ASCE,* **104,** *ST12,* Proc. Paper 14207, Dec. 1978, 1845-1858.

This paper examines the possibilities of identifying important engineering characteristics of structures using selected inspection and test results. Recently, methods of system identification have been used to obtain a set of differential equations or generalized impulse response functions for the representation of the dynamic behavior of a given structure. It is suggested that the characteristics to be identified in this way can include such functions as the damage and reliability of the structure at the time of the test and inspection. The general problem of structural identification is formulated and considered. The literature on the damage function and the reliability functions of structures is reviewed and summarized. Possible applications of various testing procedures, including nondestructive and proof-load tests for structural identification purposes, are also considered. Finally, the potentially practical implementation of such a methodology is suggested.

● 7.3-36 **Mitigation of seismic hazards in existing unreinforced masonry wall buildings: performance of undesigned and modified elements; evaluation of modification methods,** Kariotis, Kesler, and Allys, South Pasadena, California, Mar. 31, 1978, 34. (NTIS Accession No. PB 278 927)

The feasibility of using a simple methodology to mitigate seismic hazard in unreinforced masonry wall structures is investigated. Performance of the undesigned elements that participate in structural response and current modification methods applied to these elements are evaluated. Interviews with technical personnel and a survey of masonry buildings were conducted in representative areas of the United States that may be subject to moderate to severe ground motion. The survey indicates commonality of construction methods, range of building dimensions, and use of masonry materials.

Analytical studies of a structure with a flexible horizontal diaphragm were made using typical design procedures and simplified mathematical models subjected to various ground motions. The studies indicate that structural response of vertical and horizontal elements can be defined by simple parameters. At present, the state of stress in elements under dynamic loads cannot be determined within reasonable bounds by typical static analysis. Additional research is needed to formulate rules of analysis.

Prior and current research of the material properties of masonry were reviewed to extract general data applicable to unreinforced masonry. Current methods of sampling and testing of unreinforced masonry were reviewed to ascertain whether properties obtained by experimentation can predict the multiplicity of failure stresses that are related to failure modes. Static testing of unreinforced masonry is proposed to determine the behavior of materials that have a wide variation of mortar and masonry unit strength. Mathematical analysis and dynamic testing of large-scale wall panels are proposed to determine the performance of unreinforced walls for forces normal to their plane.

It is concluded that a methodology for mitigation of seismic hazard in unreinforced masonry structures can be developed. Test programs related to proposed research will furnish definitive data that will improve analysis of undesigned elements. Analyzing the need for retrofitting is cost effective. Current retrofit and modification methods, as well as new techniques for strengthening unreinforced masonry, have applicability.

● 7.3-37 Cagley, J. R., **Seismic hardening of unreinforced masonry walls through a surface treatment,** Martin and Cagley, Rockville, Maryland, Mar. 31, 1978, 28. (NTIS Accession No. PB 278 930)

The objective of this project was to determine the feasibility of using a coating or surface treatment on unreinforced masonry walls to achieve seismic hardening. Methods for reinforcing masonry are evaluated, and test data of unreinforced masonry are reviewed. Coatings are researched and anticipated required stress levels are determined. It is concluded that the use of surface bonding cement may be an economical and expedient solution.

● 7.3-38 Federation Internationale de la Precontrainte, **Recommendations for the design of aseismic prestressed concrete structures,** *FIP/7/1,* Cement and Concrete Assn., Slough, England, Nov. 1977, 28.

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Three reports are presented in this volume. The first, "Recommendations for the Design of Aseismic Prestressed Concrete Structures," considers earthquake loads at two levels of risk, the characteristic moderate earthquake and the characteristic severe earthquake including the possibility of a maximum credible earthquake. Limit state design methods are proposed and design values for loads, strengths of materials, and prestress are suggested.

The second report contains a series of explanatory comments on the recommendations. The third report is concerned with the use of unbonded tendons in seismic-resistant prestressed concrete structures. In seismic areas, there is a great deal of controversy over the necessity to grout post-tensioned tendons. However, at present, there is insufficient evidence to show that grouted tendons are more satisfactory than unbonded tendons in structures subjected to seismic forces. The importance of this point is stressed and the need for further investigation of results in practice is urged. This report reviews recent research results and design proposals in order to establish a current state-of-the-art report of the use of unbonded tendons. Although no specific design recommendations are presented, it is hoped that this particular report will help designers arrive at simple and universally applicable design concepts in designing seismic-resistant unbonded prestressed concrete structures.

● 7.3-39 Wakabayashi, M., **Seismic design of mixed steel concrete structures in Japan,** *Stability of Structures under Static and Dynamic Loads,* Proceedings of International Colloquium, Washington, D.C., May 17–19, 1977, American Society of Civil Engineers, New York, 1977, 40–58.

The seismic-resistant design in Japan of mixed steel concrete structures, particularly steel-reinforced concrete structures, is discussed. Presented are the static design method based on seismic intensity, the Architectural Inst. of Japan method for assessing the seismic safety of statically designed structures of low or medium height, and the results of an elastic-plastic dynamic response analysis. The paper concludes with a discussion of the elastic-plastic behavior of steel-reinforced concrete members, connections, and frames and problems for future investigation.

● 7.3-40 Priestley, M. J. N., **Seismic design of masonry structures,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 178–195. (For a full bibliographic citation see Abstract No. 1.2–3.)

The current status of the seismic design of masonry structures is reviewed. It is noted that many codes of practice require elastic design for masonry, but specify seismic lateral load levels which imply significant post-yield ductility. It is recommended that a rational design approach incorporating the concept of ductility be adopted. Recent experimental work on cyclic testing of masonry units is reviewed, and limits to available ductility are proposed. Different masonry structural systems, including cantilever shear walls, perforated walls, and masonry infilled frames, are discussed and evaluated. The feasibility of base-isolation to reduce seismic forces in masonry structures is briefly discussed.

● 7.3-41 Ang, A. H.-S. and Wen, Y. K., **Risk and safety analysis in design for natural hazards protection,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 1–17. (For a full bibliographic citation see Abstract No. 1.2–3.)

An approach to the risk-based analysis of safety of structures and facilities against the extreme forces of natural hazards is described. The components of the basic methodology are outlined, and applications to wind and earthquake are emphasized. References to more comprehensive works are provided. The implications for design to ensure a desired level of protection (in terms of probability) against natural hazards are indicated.

● 7.3-42 Cismigiu, A. I. and Dogaru, L. C., **A tentative for aseismic design of reinforced concrete columns,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 3, Paper 3-38, 1978, 301–308.

Following two strong Romanian earthquakes (Vrancea, 1940 and 1977), a large number of RC columns erected between 1925 and 1940 showed fatigue, brittle degradation, and collapse phenomena. From field investigations of hundreds of typical damage cases, the authors concluded that damage was a result not only of poor construction but also of poor design. The authors point out that only recently has there been an awareness of the elements of safe design of RC columns and that a broader discussion on aseismic design of RC columns has become necessary.

7.3-43 Hawkins, N. M., **State-of-the-art report on seismic resistance of prestressed and precast concrete structures (part 2),** *Prestressed Concrete Institute Journal,* 23, *1,* Jan.-Feb. 1978, 40–59.

Presented are the results of analytical and experimental studies concerning the seismic resistance of prestressed and precast concrete structures and their subassemblages. The significance of the studies is assessed, and research needs for structures are identified. Separate sections are presented for prestressed and precast concrete. Prestressed concrete was examined in the Nov.-Dec. issue of the *PCI Journal.* This report considers precast concrete and updates a state-of-the-art paper developed for a Workshop on Earthquake Resistant Reinforced Concrete Building Construction held at the Univ. of California at Berkeley in July 1977. Eight other papers dealing with prestressed and

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precast concrete buildings were presented at that workshop. Information from these eight papers is incorporated into this report along with research recommendations developed at the workshop for prestressed and precast concrete.

● 7.3-44 Hall, W. J., **Current trends in the seismic analysis and design of structures and facilities,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 147-163. (For a full bibliographic citation see Abstract No. 1.2-3.)

This paper reviews some of the current trends in the seismic analysis and design of structures and facilities. Design and analysis philosophy and the basic function of design codes and standards are discussed. Next follows a discussion of the philosophy of selection of the earthquake hazard for major facilities such as nuclear reactors and pipelines, followed thereafter by a description of the highlights of the recent Applied Technology Council study dealing with the development of recommended comprehensive seismic design provisions for buildings. The paper concludes with a brief summary of some recent studies on the design and analysis of lowrise and highrise buildings carried out recently at the Univ. of Illinois, and some observations pertaining to needed studies in the future.

● 7.3-45 Kato, B., **Seismic design in Japan,** *Stability of Structures under Static and Dynamic Loads,* Proceedings of International Colloquium, Washington, D.C., May 17-19, 1977, American Society of Civil Engineers, New York, 1977, 1-6.

● 7.3-46 **Repair of buildings damaged by earthquakes,** *ST/ESA/60,* Dept. of Economic and Social Affairs, United Nations, New York, 1977, 124.

This report describes in simple terms some methods of repairing buildings damaged by earthquakes. Attention is given to plain and reinforced concrete structures and to masonry and adobe buildings. Steel and wood structures are not considered because of characteristics which tend to necessitate their replacement rather than their repair. Diagrams are presented of repairs to plain concrete, reinforced concrete, mortar-block and brick masonry, and adobe construction.

● 7.3-47 Derecho, A. T., Schultz, D. M. and Fintel, M., **Analysis and design of small reinforced concrete buildings for earthquake forces,** *Engineering Bulletin EB004.06D,* Portland Cement Assn., Skokie, Illinois, 1978, 43.

This report concerns the analysis and design of small reinforced concrete buildings for earthquake resistance. It outlines the basic considerations involved in earthquake-resistant design and presents recommendations for analysis and design, along with suggestions pertaining to construction, that will ensure safe, economical small buildings. Typical examples are worked out in detail to illustrate design principles. Much of the discussion and the illustrative examples given in this booklet are based on the latest editions of the Uniform Building Code (1976 edition) and Building Code Requirements for Reinforced Concrete (ACI 318-77).

● 7.3-48 Muto, K. *et al.*, **Earthquake resistant design of tall reinforced concrete buildings** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 107, Nov. 1978, 849-856.

This paper describes an earthquake-resistant design method for tall reinforced concrete buildings. Dynamic design criteria for such buildings are established taking into account earthquake intensities and building behavior. A vibration model with nonlinear restoring force characteristics is developed. The ultimate strength of the model is determined from empirical and theoretical equations. Earthquake response analyses are carried out for structures subjected to severe earthquakes with 0.25 g and 0.40 g maximum accelerations. Ductility requirements, such as cracking of concrete and yielding of reinforcing bars are anticipated and discussed from the viewpoint of the overall safety of the structures.

● 7.3-49 Ohashi, K., **Design of earthquake-proof architectural construction from documentation's point of view. (equations of motion for making low-RC-constructions secure)** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 105, Nov. 1978, 833-840.

● 7.3-50 Minai, R., **On the reliability-based optimum seismic design of building structures,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 156, Nov. 1978, 1241-1248.

A methodology is developed for the reliability-based optimum seismic design of structures on the basis of seismic risk analysis and stochastic seismic response analysis. By taking into account the seismicity of a region as well as a prescribed time period for use of a structure, design earthquakes for both the elastic allowable and elastoplastic ultimate seismic design principles are determined. The principles are established in terms of a spectral density function and the duration of ground acceleration excitations at a site together with the associated reliability required in the stochastic seismic response analysis for the respective design principle. Under the assumption of high statistical dependence among the safety margin responses of the structural system to seismic excitations, an optimum

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seismic design procedure for multidegree-of-freedom structural systems is formulated. The design procedure can be used to evaluate the second-order statistics of both safety-measurable responses and the corresponding capacities of the structures. The formulation minimizes the nonuniformity of component failure probabilities and the constraints of system failure probabilities for the two design earthquakes.

● 7.3-51 Cheng, F. Y. and Srifuengfung, D., **Discussion on optimality criteria for seismic tall buildings with specific natural frequencies,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 157, Nov. 1978, 1249–1256.

This paper investigates the optimality criterion method of energy distribution for seismic structural design with frequency constraints. A typical numerical example explores the pitfalls of the method for certain types of structures.

● 7.3-52 Shibata, H. *et al.*, **On decline of reliability of response analysis,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 29–36.

Important structures in industrial facilities, such as nuclear power stations and chemical engineering plants, are designed based on their seismic response analyses. These analyses are usually performed using a collection of horizontal ground acceleration time histories, for example, from the El Centro 1940, the Taft 1952, and the Hachinohe 1968 earthquakes. However, even if the number of earthquakes in a set is more than three, the result of the response analysis still fluctuates. The response spectrum is uncertain, and the dispersion factor (the ratio of standard deviation to the mean) is sometimes over 50%. It can therefore be said that the probable earthquake loading is unreliable. In this paper, the authors mention that there are several other uncertainties in determining earthquake loadings and that these uncertainties are especially significant for large structures in recently built industrial facilities, resulting in a decline in their over-all design reliability. The paper points out that some tower-type structures may suffer more from torsional ground motions than from horizontal ground motions and that low damping structures may resonate to one of the dominant frequency components of the ground motion.

● 7.3-53 Eisenberg, Ya. M., Neiman, A. I. and Abakarov, A. D., **Optimal states and mathematical models of structures determined from the seismic risk problem,** *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 467–471.

A procedure for assessing seismic risk is proposed. In terms of the optimization of the seismic risk, suggestions are made for a more efficient distribution of the seismic protection costs. The problem of defining design models of structures and earthquake ground motion for the optimal design of structures to be constructed in seismic zones is considered.

● 7.3-54 Riddington, J. R. and Smith, B. S., **Composite method of design for heavily loaded wall-beam structures,** *Proceedings, The Institution of Civil Engineers,* Part 1, 64, Feb. 1978, 137–151.

A design method is presented for heavily loaded wall-beam structures. The method was developed particularly for structures with masonry walls and steel beams and accounts for their composite behavior. The composite action consists of the wall arching across the span with the beam acting as a tie. Its effect is to concentrate the wall stresses and reduce the beam moments. By the use of wall-beam relative stiffness as a basis for predicting the distribution of interaction stresses, the maximum wall stresses and the beam bending moments are estimated. The estimates are then used for designing the components. Designing a wall-beam structure to satisfy both wall and beam stresses is inherently an iterative problem. However, the method proposed is direct, simple, and yet rational in accounting for arching and the influence of the wall-beam relative stiffnesses.

● 7.3-55 Vannoy, D., Harvey, H. E. and Colville, J., **Case study—computerized design for load bearing masonry,** *North American Masonry Conference Proceedings,* Paper No. 81, 25. (For a full bibliographic citation, see Abstract 1.2-12.)

The Locust House, a seven-story, load-bearing masonry building, is analyzed using a computer program developed by the Masonry Inst. of Maryland. Construction of the building was to begin in the spring of 1978 and to be completed 15 months later. The building, which will be located in Westminster, Maryland, will have 73,500 sq ft of space and will provide government-assisted housing for the elderly.

This paper illustrates how data for a typical building are prepared for input into the computer program by using the Locust House as a case study. The results give the required compressive strengths for all walls for the loading combinations used in a design. Based on the case study, this paper illustrates and discusses the changes made in the floor plan and wall dimensions to develop an effective and economical final design for Locust House with the use of the computer program.

● 7.3-56 Person, O. F., **How the high lift grouting system was developed,** *North American Masonry Conference Proceedings,* Paper No. 62, 8. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper presents information about the inception and development of the high-lift grouting system for masonry construction. It also describes the testing project: "The Method of Reinforced Concrete in Masonry Construction Using High-Lift Grout System." This report is based upon the experience of a masonry contractor. Cases illustrating the use of the high-lift system, and recommendations for its successful application in masonry construction, are included.

● 7.3-57 Mock, J. R., **Modern loadbearing masonry construction in the western United States,** *North American Masonry Conference Proceedings,* Paper No. 110, 19. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper explains the concept and development of the standards for reinforced concrete masonry (concrete block) construction. Examples of construction projects in the western United States illustrate the basic concepts of this new use of masonry. The advantages of the system are discussed.

● 7.3-58 Colville, J. and Vannoy, D., **Rational analysis of masonry structures,** *North American Masonry Conference Proceedings,* Paper No. 90, 15. (For a full bibliographic citation, see Abstract 1.2-12.)

A procedure for the rational analysis of load-bearing masonry structures is developed. This procedure follows the *Building Code Requirements for Engineered Brick Masonry* (Aug. 1969), published by the Brick Inst. of America, and the *Specification for the Design and Construction of Load-Bearing Concrete Masonry* (Feb. 1975), published by the National Concrete Masonry Assn. Equations are presented for determining the distribution of lateral loads on resisting shear walls. The equations take into account that some walls may not extend the full height of a building and that wall properties may change from floor to floor. A strength analysis is performed. The analysis indicates the required compressive strength of each wall at each floor level for seven critical combinations of vertical and lateral loads. The analysis also considers the effects of slenderness and eccentricity caused by gravity loading. The procedure described in the paper has been incorporated into a computer program which is available from the Masonry Inst. of Maryland.

● 7.3-59 Amrhein, J. E., **Progressive collapse of masonry structures,** *North American Masonry Conference Proceedings,* Paper No. 94, 10. (For a full bibliographic citation, see Abstract 1.2-12.)

Progressive collapse and catastrophic failure are of increasing concern to engineers and governmental regulatory bodies. This paper outlines types of progressive collapse and provides design parameters that might be considered to prevent such collapse. Loading conditions and element failure are discussed, and general recommendations are made for tying together structural elements.

● 7.3-60 Hendry, A. W., **Some fundamental factors in the structural design of masonry buildings,** *North American Masonry Conference Proceedings,* Paper No. 86, 15. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper reviews a number of factors underlying the structural design of masonry buildings. Considerations affecting the plan arrangement of walls are first considered. Closely allied to this is the requirement to ensure general strength of a building and, in particular, the avoidance of collapse resulting from accidental damage. The choice between reinforced and unreinforced masonry is discussed and the possibility of using reinforced or prestressed elements in masonry construction is recommended. Masonry building codes are now being framed in terms of the limit states approach; this has required the selection of appropriate partial safety factors. Recent theoretical work by Macchi and by Beech is referred to and reference is made to the new British Code of Practice, due to be published in 1978. The analysis of masonry structures is considered in relation to vertical and lateral loads. Somewhat crude methods currently are used in design calculations; but, as a result of recent research work, more rational procedures will soon be available.

● 7.3-61 Hill, Jr., L. A. and Chasey, Jr., R. H., **Automated design of multistory masonry shear wall structures,** *North American Masonry Conference Proceedings,* Paper No. 83, 17. (For a full bibliographic citation, see Abstract 1.2-12.)

This paper discusses a computer program for the automated, practical design of multistory masonry shear wall structures. Automated techniques provide an economic means for data-controlled design, without the need to learn a problem-oriented language. Structured programming techniques are used to simplify revision and/or replacement of subroutines necessitated by code changes and to simplify improvements and refinements in design and analysis methods. The overall program configuration included programming from the top down to ensure that the data structure and program modules consistently maintained integrity and flexibility. Program modules, however, were consistently tested using programming from the bottom up to ensure the accurate performance of assigned tasks under all possible conditions.

User input is minimized by utilizing the typically repetitious nature of both horizontal and vertical structure geometry. User options provide data-controlled flexibility of design criteria, unit material and labor costs, seismic and wind zones, material strengths, allowable stresses, etc. Working stresses are used in the design of all structural elements and connections. Iterative selections are checked against applicable code requirements and revised as necessary. The 1976 Uniform Building Code is used but care is taken to allow for the incorporation of future code revisions, including the method of analysis based on artificial seismic time histories. The output conforms to standard design office procedures and includes user data-specified selectivity. In general, input data is checked for reasonableness and repeated to guard against gross errors. Masonry thicknesses and reinforcing steel details (i.e., design results) are output in a well-organized format for providing structural drawings. Analyses include load combinations and stress checks for all elements. This output is in a form to facilitate checking by the engineer and regulatory agencies which must approve the plans. A bill of materials and a cost estimate are also provided.

● 7.3-62 Pyle, D. T., **An application of thin wall masonry,** *North American Masonry Conference Proceedings,* Paper No. 80, 5. (For a full bibliographic citation, see Abstract 1.2-12.)

Single-wythe masonry walls, coupled with concrete floor and roof framing systems, are especially suited to construction of multi-unit residential projects and small office buildings. In spite of the current popularity of single-wythe construction, it presents considerable design difficulties to the architect and structural engineer. A construction system and a special masonry-to-concrete connection, using standard construction materials and procedures, are proposed to solve some of the design problems and to reduce construction cost.

● 7.3-63 Klausmeier, R. D., **Surface bonding cement: a new technology for masonry,** *North American Masonry Conference Proceedings,* Paper No. 65, 11. (For a full bibliographic citation, see Abstract 1.2-12.)

A new technology has been added to the masonry industry—surface bonding cement. Surface bonding cement is composed of fiberglass reinforced concrete that is used to bond hollow-unit masonry without the use of mortar. A 1/8-in.-thick, glass-reinforced skin on each side of a wall bonds the units and seals the masonry in one step. A row of concrete units is placed in a mortar bed. Subsequent rows of dry units are stacked. The dry walls are dampened and the surface bonding is troweled on. The surface bonding cement gains much of its strength within 24 hours. Tests have been conducted to establish the moisture penetration resistance, fire resistance, as well as the various structural characteristics. The National Concrete Masonry Assn. has issued recommended design allowances and a short-form specification has been developed.

● 7.3-64 Davis, H. A., **The Center for Educational Development—a medium scale seismic upgrading,** *North American Masonry Conference Proceedings,* Paper No. 42, 15. (For a full bibliographic citation, see Abstract 1.2-12.)

During the 1960s many substantial buildings in San Francisco were vacated or abandoned by industrial and commercial occupants, creating a surplus of unused floor space. Most of these buildings were old, poorly ventilated, without adequate parking facilities, and seismically hazardous, thereby becoming possible liabilities to their owners rather than assets. Far West Lab. for Educational Research and Development obtained a federal grant to relocate in San Francisco and purchased a 43-year-old warehouse building at 15th and Folsom Streets. Proposed use of the space included a school (part of the San Francisco School District), offices, and retail facilities for selected light industry.

The seismic upgrading requirements of Title 21 were met by using gunite backing on the brick walls and new concrete wall elements. By adding major grade beams attached to the existing structure, it was possible to use the existing pile foundations. Disruption to the existing structure was kept to a minimum by drilling hundreds of holes of varying size and location in the existing concrete and brick fabric of the building. These holes were then filled with epoxy bonding agents and reinforcing bars. The exterior appearance of the building was maintained virtually unchanged by placing all new element., on the inside. The flexibility of the interior space was maximized by locating all shear elements on the exterior perimeter of the building.

● 7.3-65 **A rational approach to damage mitigation in existing structures exposed to earthquakes,** Earthquake Engineering Systems, Inc., San Francisco, May 1978, 88.

The work presented in this report is Phase I of a two-phase study. The purpose of this report is to study the feasibility of developing a rational decision analysis methodology to evaluate possible modification schemes for existing buildings exposed to a predicted earthquake. The parameters involved in such a methodology are identified. Available procedures to determine the expected earthquake hazard at a given site are studied, and a methodology to apply the results of these procedures to the decision-making process is presented. A procedure to calculate the damages to various components of a building caused by different levels of ground shaking is developed. A computer program called DAMSTAT is developed to automate the calculation steps for the proposed methodology.

● 7.3-66 Kato, B. and Akiyama, H., **Damage distribution law of shear-type multi-story structures under earthquakes** (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 61-68.

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

The total energy input into a structure excited by earthquake ground motion is little affected by the strength and deformation characteristics of the structure. The distribution of damage, however, depends largely on the distribution of the strength of the structure. For the practical purpose of structural design based on the ultimate strength design concept, it is necessary to predict the concentration of damage which causes the collapse of the weakest story in a multistory structure.

In this paper, a basic law governing the distribution of damage in shear-type multistory steel buildings is derived through numerical response analyses and is expressed in a simple empirical formula. Strain-hardening of structural steels is a desirable way of mitigating damage concentration. On the other hand, deterioration of the restoring forces of the skeleton because of instability such as local buckling and flexural torsional buckling of structural members accelerates the concentration of damage. Thorough understanding and quantitative evaluation of these pheonomena can be made by the analytical application of the proposed empirical formula.

7.3-67 Allen, F. H. and Darvall, P. LeP., **Lateral load equivalent frame for flat plate structures,** *Civil Engineering Transactions,* **CE 20,** *1,* 1978, 60-66.

Theoretical effective width coefficients for flat plate structures are presented for a wide range of plate aspect ratios and column cross section aspect ratios. Experimental results are given which confirm the theoretical values of the effective width coefficient. A new lateral load equivalent frame is proposed that uses the theoretical effective width coefficient. Three hypothetical buildings under lateral load are analyzed for story sways using the equivalent frames permitted by the codes and are compared to the results for the proposed lateral load equivalent frame. It is shown that there is a wide variation in results for the frames chosen, deviating significantly from what the authors believe is the correct theoretical solution.

● 7.3-68 Galunic, B., Bertero, V. V. and Popov, E. P., **An approach for improving seismic behavior of reinforced concrete interior joints,** *UCB/EERC-77/30,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1977, 116. (NTIS Accession No. PB 290 870)

The interior joints of reinforced concrete moment-resisting frames are vulnerable to severe bond deterioration of the beam main bars passing through the column during severe cyclic loadings such as might occur in a major earthquake. In conventionally designed interior joints, cracks form on the beams at both faces of a column and, if their main reinforcing bars are sufficiently strained, the bars can be simultaneously pulled from one side and pushed from the other. The bars could then slip through the columns, greatly reducing the stiffness in the beam-column assemblies. An approach is suggested for obviating this problem by avoiding the high straining of the bars at the face of the column by forming the plastic hinges with the resulting significant cracking away from the column faces. Two schemes for achieving this by proper detailing of the main beam reinforcement are reported. One such scheme involves bending some of the main beam bars at a properly computed distance from the column. In the alternative scheme, some of the bars are cut off at a properly determined distance from column faces. Experimental results show that the approach of forcing the development of the plastic hinges away from the column is very promising for solving the problem of severe bond deterioration of the main bars passing through the column, and that, for the subassemblage tested, either of the schemes used gives excellent results.

● 7.3-69 Paz D., C. M., **Earthquake resistant design of wooden structures,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 217-243.

● 7.3-70 Paulay, T., **A consideration of P-delta effects in ductile reinforced concrete frames,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *3,* Sept. 1978, 151-160.

The likely effects are examined of secondary moments due to a gravity load, which is laterally displaced during inelastic seismic story drift, upon ductile reinforced concrete frames. Existing building code recommendations and design procedures relevant to the phenomenon are briefly reviewed. The probable effect of P-delta moments on inelastic dynamic frame response is discussed. By the use of illustrations, various design considerations are presented. It is suggested that the strength demand caused by the P-delta effects can be met if the demand exceeds 15% of the ideal lateral load-carrying capacity of a subframe. By comparing the elastic and inelastic deformations of a frame resulting from earthquake loading, an estimation is made of critical inelastic drifts in the lower half of the frame. This is subsequently used to quantify the problem with the aid of the "stability index." A quantitative evaluation of P-delta effects for an 18-story frame is illustrated in the appendix.

● 7.3-71 Priestley, M. J. N., Evison, R. J. and Carr, A. J., **Seismic response of structures free to rock on their foundations,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *3,* Sept. 1978, 141-150.

The possibility of foundation rocking of shear wall structures designed to meet the requirements of NZS 4203 is discussed. Housner's theory for the free rocking of a rigid block is compared with experimental results from a simple structural model with a number of different foundation conditions. A simple design method for assessing maximum

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

rocking displacements, using equivalent elastic characteristics and a response spectra approach, is proposed and is compared with the results from simulated seismic excitation of the model using an electro-hydraulic shaking table. A typical design example is included.

● 7.3-72 Razani, R., **Seismic protection of unreinforced masonry and adobe low-cost housing in less developed countries: policy issues and design criteria,** *Disasters,* 2, 2/3, 1978, 137–147.

This paper discusses loss of life caused by the seismic collapse of lowrise unreinforced masonry and adobe buildings. The amount of research effort spent on the seismic study of these types of buildings is not in proportion to the high level of human loss caused by their destruction. The reasons for the popularity of this type of construction in less developed countries (LDCs) are discussed. It is shown that this type of construction will continue to be the major type of construction for low-cost housing in most LDCs for many decades to come. The causes of roof collapse of these buildings under earthquake action are described. It is concluded that the use of advanced technology and costly methods for earthquake-resistant strengthening of masonry buildings is not feasible in most LDCs. The need for development of a suitable earthquake protection policy and design criteria for low-cost unreinforced masonry and adobe housing in LDCs is discussed, and some findings are presented. Some principles and methods for designing these types of houses to resist seismic collapse are discussed. Also, some low-cost methods for reduction of earthquake damage are given. The scope of research and development needs in the areas of improving the mechanical properties of low-cost construction materials, developing a low-cost, lightweight roofing system, and improving the design methods for this type of construction are described.

● 7.3-73 Liu, T. C., O'Neil, E. F. and McDonald, J. E., **Maintenance and preservation of concrete structures: annotated bibliography, 1927-1977,** *Report 1, Technical Report C-78-4,* Concrete Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Sept. 1978, 418.

Contained in this bibliography are 826 annotated references on maintenance and preservation of concrete structures. The references cover the period from 1927 to 1977 and include the subjects of durability and causes of deterioration, evaluation of the condition of existing structures, and maintenance and repair materials, procedures, and techniques. A subject index and an author index are provided.

● 7.3-74 Tyler, R. G., **Tapered steel energy dissipators for earthquake resistant structures,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 11, 4, Dec. 1978, 282–294.

The paper describes the testing and design of tapered-steel cantilevers used as energy dissipating devices, manufactured from either round bars or plates, which can be used in isolation systems to protect buildings or bridge decks against seismic forces. The steel cantilever energy absorber is a simple device which can be manufactured by means of standard engineering practice from steel supplies normally available.

● 7.3-75 Megget, L. M., **Analysis and design of a base-isolated reinforced concrete frame building,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 11, 4, Dec. 1978, 245–254.

The paper describes the dynamic and static analyses and design of a four-story ductile reinforced concrete frame structure isolated from its foundation by elastomeric bearings which incorporate 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 isolated building's response (shears, plastic hinge demands, and interstory drifts) are detailed. Differences from conventional ductile design and detailing as well as design recommendations are included.

● 7.3-76 Mostaghel, N. and Khojasteh-Bakht, M., **Rural housing plan to mitigate earthquake effects** (in Persian), *Report 5, EEC-78.3,* Earthquake Engineering Center, Pahlavi Univ., Shiraz, Iran, Oct. 1978, 19.

This paper presents a proposed plan for rural housing to reduce the earthquake effects in rural seismic areas around the Kavir in Iran. The plan is such that the villagers can build their own housing units using available local construction materials and traditional techniques.

● 7.3-77 Lybas, J. M., **Methods for seismic strengthening of buildings,** *Interim Report M-249,* Construction Engineering Research Lab., U.S. Army, Champaign, Illinois, July 1978, 29.

This report is designed for use by engineers in strengthening buildings to increase their seismic resistance. Criteria are provided for determining the suitability of and for using specific strengthening methods. Strengthening methods used in the past are reviewed, with emphasis given to those most applicable to the needs of the U.S. Army. Detailed guidelines for the application of two methods—pneumatic application of concrete and use of epoxy compounds—are provided. The advantages and disadvantages of each method are discussed.

● 7.3-78 Arya, A. S., **Influence of natural disasters (earthquakes) on educational facilities,** *Earthquake Engineering Studies EQ: 77-14,* School of Research and Training in

Earthquake Engineering, Univ. of Roorkee, Roorkee, India, Dec. 1977, 3 vols., 340.

This is a final report submitted to the Educational Facilities Div. of the United Nations Educational, Scientific and Cultural Organization. The main objective is to study the effects of earthquakes on school buildings in the Asian countries of Afghanistan, Bangladesh, Burma, India, Indonesia, Iran, Iraq, Malaysia, Nepal, Pakistan, Philippines, Thailand, and Turkey. The contents include: Part 1—Collection & Analysis of Available Information; Part 1a—Annotated Bibliography; Part 2—Strengthening of Buildings Against Earthquakes.

7.4 Design and Construction of Nuclear Facilities

● 7.4-1 Christian, J. T., Borjeson, R. W. and Tringale, P. T., **Probabilistic evaluation of OBE for nuclear plants,** *Journal of the Geotechnical Engineering Division, ASCE,* **104,** *GT7,* Proc. Paper 13904, July 1978, 907–919.

The operating basis earthquake (OBE) governs the design of many components of a nuclear power plant. Probabilistic analyses were performed to determine the OBE for the Koshkonong nuclear plant in southern Wisconsin. The area has sparse seismicity, so the data are scattered. Parametric studies indicated the effects of different recurrence rates, attenuation laws, and maximum epicentral intensities. An OBE of intensity VI (Modified Mercalli) with a corresponding peak acceleration of 0.06 g is justified. A simple analysis of the probability of recurrence of an event shows that multiple occurrences have significant probabilities when the return period of the earthquake is close to the life of the plant. The present OBE has an expected return period of about 1000 yr; for conservative assumptions, the return period is a few hundred years.

7.4-2 Fardis, M. N. and Cornell, C. A., **Containment liner seismic reliability under statistical uncertainty,** *Nuclear Engineering and Design,* **49,** *3,* Sept. 1978, 279–294.

Creation of cracks in the containment liner during an earthquake may lead to partial failure of the leak-tightness function of the liner during a subsequent accident. Within the context of an integrated accident and seismic containment reliability study, a methodology is presented for the probabilistic description of liner cracking in terms of the number of liner cracks and the total crack length as a function of the causative ground acceleration. Earthquake intensities well beyond design levels are considered, and simple behavior models are used for feasible consideration of a large number of uncertainties. This study focuses on statistical uncertainty that stems from the limited amount of available information about material properties, the actual state of the system, etc. The effects of the individual components of uncertainty and of the order in which they are introduced are analyzed.

● 7.4-3 Newmark, N. M. and Hall, W. J., **Development of criteria for seismic review of selected nuclear power plants,** N. M. Newmark Consulting Engineering Services, Urbana, Illinois, May 1978, 49.

This report discusses the criteria and principles which are of primary concern in reviewing existing nuclear facilities. The aim is not to discuss each topic in great depth but instead to place engineering concerns in perspective and to identify the major items that should be included in a review. The text begins with a general discussion of the earthquake hazard which should be used in the review. It is the authors' belief that the seismic hazard should be reevaluated for each existing plant with consideration of current U.S. Nuclear Regulatory Commission procedures. Seismic motions to be used in upgrading the plants, damping and energy absorption, and soil-structure interaction are examined, followed by a brief discussion of methods of dynamic analysis. Some specific topics are mentioned which must be considered in detail in the review process, including such items as the material properties, load combinations, response spectra, uplift, and response of equipment. A number of special topics which may require consideration in the review are listed and briefly discussed. These include fault motions, conduits, vaults and tanks, quality control, and risk assessment. The report concludes with some observations on audits and systems summaries.

● 7.4-4 Skipp, B. O. *et al.,* **Problems in the application of codes and guides to the selection of sites for nuclear power plants in Europe,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-09, 1978, 55–65.

Guidelines for nuclear power station siting pose seismotectonic problems which will require time to resolve. Site acceptability is linked to Quaternary fault movement with differing implications in northern and southern Europe. With such aspects in mind, preliminary investigations can minimize the risk of selecting ultimately unacceptable sites for intensive study.

● 7.4-5 Slattery, W. J., **Index of U.S. nuclear standards,** *NBS Special Publication 483,* Inst. for Applied Technology, U.S. National Bureau of Standards, Washington, D.C., Aug. 1977, 127.

The index contains the permuted titles of more than 1200 nuclear and nuclear-related standards, specifications, test methods, codes, and recommended practices published by 34 U.S. government agencies, technical societies, professional organizations, and trade associations. Each title can be found under the key words it contains. The key words are arranged alphabetically. Each entry includes the date of publication or last revision, the standard number, an acronym designating the standards-issuing organization, any cross reference standard number, and the price.

7.4-6 Tagart, Jr., S. W., **Seismic analysis—what goal?**, *Nuclear Engineering and Design*, **46**, *2*, Apr. 1978, 417-427.

The seismic analysis of nuclear components is characterized by extensive engineering computer calculations to satisfy both the component standard codes, such as ASME III, and federal regulations and guides. The current nuclear seismic design procedure has evolved erratically and continues to change as improved technology leads to changing standards and guides. The dominant trend is a monotonic increase in the overall conservatism with time, causing a similar trend in costs of nuclear power plants. Ironically, improvements in the state-of-the-art are feeding a process which is eroding the very incentives that made nuclear power attractive in the first place. This paper examines the cause of this process and suggests that a realistic goal is needed which addresses the overall uncertainty of the seismic design process.

7.4-7 Augustin, W. *et al.*, **A complex study on the reliability assessment of the containment of a PWR, parts I-III**, *Nuclear Engineering and Design*, 48, *2&3*, Aug. 1978, 563-593.

The study objective is to contribute to the development of methods for the quantification of the risk of nuclear power plants. For this purpose a reliability analysis of a structural component, i.e., a reactor containment structure, is carried out. Detailed information in various fields had to be developed and compiled. The project consists of three parts: Part I concentrates mainly on the analysis of the load condition of the steel hull following a loss of coolant accident. Part II deals with the material aspects of the design properties of containment steels, and the behavior of concrete under impact load conditions is discussed. Part III is concerned with external load conditions and with assembling the information of the previous parts for a reliability analysis. The methodology is exemplified by applying the general and theoretical results to the containment of the PWR-plant Biblis B.

● 7.4-8 Skreiner, K. M., Fitzgerald, E. M. and Test, L. D., **Seismic qualification of Class 1E equipment today**, *Journal of Environmental Sciences*, Jan.-Feb. 1978, 19-23. (Presented at the 23rd Annual Technical Meeting of the Inst. of Environmental Sciences, Los Angeles, Apr. 1977.)

Seismic qualifications of Class 1E equipment using the required response spectrum and full-scale testing has been reviewed. Significant developments include a move towards the use of multi-frequency test motions and the development of a proposed standard for the seismic testing of relays. With the introduction of the concept of a standard design for nuclear power plants, an extremely conservative broad-band, worldwide required response spectrum has been published for the seismic qualification of Class 1E equipment using only one test.

Some of the problems associated with the introduction of high degrees of conservatism are described using the peak g level of the amplified region and the zero period acceleration of the response spectrum. A second method of assessing the severity of a seismic motion using one number employs the concept of the spectrum intensity.

It is concluded that equipment and existing shaking table limitations will not allow the conservative response spectrum described above to be achieved in practice. Alternate methods currently used to successfully produce the desired end result in a practical manner are described. With more application of these methods by the industry, it is expected that standardized test procedures will be developed.

● 7.4-9 **Assessment of seismic analysis procedures for LMFBR in-core components**, *SAN-1011-118*, Agbabian Assoc., El Segundo, California, June 1977, 60.

This report assesses the state-of-the-art dynamic seismic analysis procedures for in-core components of liquid metal fast-breeder reactors. Both United States and foreign literature is reviewed and discussions with technical personnel presently performing seismic design analyses of reactor in-core components are included. The investigation reveals that one- and two-dimensional analyses are currently being used with uncoupled horizontal and vertical input motions 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 generally is not 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) has been demonstrated 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. The analysis procedure should consider three components of input motion simultaneously as the traditional

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approach, which uses three separate models with a superposition of the results, is not valid for the treatment of nonlinear behavior. Experimental determination of the effects of frictional forces and fluid drag forces on the in-core components is also recommended.

● 7.4-10 Grant, J. M. and Wu, A. Y., **The use of concrete unit masonry in nuclear power plants,** *North American Masonry Conference Proceedings,* Paper No. 63, 16. (For a full bibliographic citation, see Abstract 1.2-12.)

Concrete unit masonry (CUM) has found increasing acceptance and utilization in the design and construction of nuclear power plants. Its use overcomes the inflexibilities of poured-in-place concrete when a construction schedule simultaneously involves both engineering design and field construction. CUM allows the delayed installation of walls and partitions to accommodate temporary construction access openings and postpones the determination of wall penetrations for cables, ducts, and pipes otherwise needed for the early installation of poured-in-place concrete. Stringent criteria unique to nuclear power plant construction for seismic integrity, radiation shielding, and for barriers against fire, flooding, gaseous incursion and pressurization, as well as against some forms of missiles, are satisfactorily accommodated by CUM systems derived from available materials and components. Certain masonry systems used in normal construction applications are generally not suitable for the demands of nuclear work.

● 7.4-11 New Zealand Atomic Energy Committee, Working Group for Seismic Effects on Nuclear Installations, **Seismic effects on nuclear installations,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *3,* Sept. 1978, 161-180.

Portions of the report of the New Zealand Atomic Energy Committee Working Group for Seismic Effects on Nuclear Installations to the 1977 Royal Commission on Nuclear Power are excerpted. The purposes of the group are (1) to examine and report on problems relating to design requirements and construction of nuclear reactor installations in New Zealand to resist seismic effects, and (2) to recommend such design requirements and safety regulations for inclusion in New Zealand nuclear reactor installation specifications. The following sections of the report are either excerpted or completely reproduced: Introduction and Summary, Recommendations, Potential Hazards from Earthquakes, Seismic Risk in New Zealand, Criteria for Design and Assessment, and Geological Assurance.

7.4-12 Bork, M. and Kaestle, H. J., **Seismic instrumentation for nuclear power plants: an interpretative review of current practice and the related standard in Germany,** *Nuclear Engineering and Design,* **50,** *2,* Oct. 1978, 347-352. (Presented as Paper K8/13 at the 4th International Conference on Structural Mechanics in Reactor Technology, San Francisco, Aug. 15-19, 1977.)

The German nuclear safety standard KTA 2201: *Design of nuclear power plants against seismic events* consists of the following parts: (1) basic principles; (2) characteristics of seismic excitation; (3) design of structural components; (4) design of mechanical and electrical parts; (5) seismic instrumentation; and (6) measures subsequent to earthquakes. This paper presents detailed requirements of the safety standard and examines its philosophy. The requirements are compared with corresponding requirements in the U.S. Instrumentation is also discussed.

7.5 Design and Construction of Miscellaneous Structures

● 7.5-1 Chopra, A. K., **Earthquake resistant design of concrete gravity dams,** *Journal of the Structural Division, ASCE,* **104,** *ST6,* Proc. Paper 13823, June 1978, 953-971.

This paper demonstrates that traditional design procedures for concrete gravity dams are unrealistic and presents a design method to ensure elastic behavior. Significant factors in the dynamic response of dams and the capacity of concrete to support dynamic stresses in tension are considered. It is pointed out that limited cracking may be allowed in concrete dams in highly seismic areas with only rare intense ground shaking. However, it is not yet possible to analytically predict with a high degree of confidence the extent of cracking and damage that may occur during intense ground shaking. The research needed to improve analysis and design procedures is identified. The design method examined in this paper can also be used to evaluate the safety of existing dams.

● 7.5-2 Jordan, C. H., **Seismic restraint of equipment in buildings,** *Journal of the Structural Division, ASCE,* **104,** *ST5,* Proc. Paper 13778, May 1978, 829-839.

Criteria and design solutions for seismic restraint of mechanical and electrical equipment in buildings are not standardized. In this paper, a review is made of the effect of earthquakes on mechanical and electrical equipment and of selected codes and standards, emphasizing those in California. Seismic restraint must be compatible with the need for some mechanical and electrical systems to be free of the structure for reasons of thermal movement and vibration control. Suggestions are made for distribution of responsibilities among mechanical and electrical engineers, structural engineers, equipment manufacturers, and contractors.

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● **7.5-3** Wang, L. R.-L. and O'Rourke, M. J., **An overview of buried lifeline earthquake engineering,** *SVBDUPS Report 1A*, Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Jan. 1978, 18.

State-of-the-art information on the behavior and design of buried lifelines, such as submerged tunnels, gas, water, and sewer distribution lines, subjected to earthquakes is examined. Specifically, a survey of pipeline damage due to past earthquakes is presented, and current design practices, analysis procedures, code provisions, and the latest published research on underground piping systems are discussed.

● **7.5-4** Traubenik, M. L., Valera, J. E. and Roth, W. H., **Effects of soil inertia forces on design of buried pipelines crossing faults,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 1105–1116.

Current methods for seismic design of buried pipelines traversing major seismogenic strike-slip fault zones generally only consider the ultimate fault displacements postulated during fault rupture. The pipe is designed to accommodate fault displacements through axial straining of the pipe. Analyses commonly used assume that the rupture process occurs slowly enough such that the soil forces acting on the pipe can be considered to be static in nature, thus neglecting any dynamic effects. This paper suggests that design of a buried pipe for fault rupture may be unconservative if dynamic forces resulting from the acceleration produced within the fault rupture zone are ignored since they may significantly increase the normally applied static forces. Soil inertia forces examined for a simple hypothesized test case are found to increase the normally predicted ultimate lateral forces, and, thus, the longitudinal frictional forces acting on the pipe by approximately 30%.

● **7.5-5** Shibata, H. and Sogabe, K., **Design criteria for oil and liquefied gas storages,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-68, 1978, 509–516.

This paper discusses proposed seismic-resistant design criteria for liquid storage vessels. A design which takes the sloshing phenomenon into account has an important effect on the acceleration response for both cylindrical and spherical vessels in interplate earthquake areas.

● **7.5-6** Parvu, R. *et al.*, **Analysis of a multi-span bridge,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-70, 1978, 525–531.

Work is presented on the seismic design of a long, multispan railway and highway bridge. Models of various parts of the structure are described. Assumptions of the seismic ground motion are discussed, with emphasis on the cross-correlation of disturbances applied to different piers. Data on the natural vibration modes and on computed conventional seismic effects (accelerations, displacements, internal forces) are presented. Techniques of analysis and engineering problems are commented upon.

● **7.5-7** Sinha, K. N. and Munsi, T. K. D., **Considerations in aseismic design of structures for refinery columns,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-69, 1978, 517–524.

Seismic design forces for elevated stagings of height 10-15 m and above supporting cylindrical towers are determined. The interaction of the steel column with the concrete-steel frame resting on piles or directly on the ground is considered, treating the system as a cantilever system. Dimensional parameters and variable damping along the height have been considered also. Average acceleration spectra curves have been used to verify the earthquake response. A concise and rapid procedure is presented for evaluating seismic loads, bending moments, and shear forces for reinforced concrete bents, rigidly tied together at the top and at the base to spread footings or to piles. The effect of the flexibility of the soil-foundation system is discussed. This flexibility influences the time period of the system. The result of several such elevated structures designed for refineries in India is provided also.

● **7.5-8** O'Rourke, M. J. and Wang, L. R.-L., **Earthquake response of buried pipelines,** *SVBDUPS Report 4,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Mar. 1978, 16.

The earthquake response of buried water and sewer lines is receiving attention because of the impact of these lifelines upon the health and safety of the people they serve. Because of the geographical extent of buried pipelines, analysis and design procedures are different than the standard procedures for building-type structures. Seismic design procedures for buried pipelines are based upon two assumptions concerning the relative motion between the pipe and the soil and the character of the seismic waves. Specifically, it is assumed that there is no relative motion between the pipe and the soil and that the shape of the seismic waves does not change as it traverses the pipeline. These assumptions, which form the basis for the presently available seismic design procedures for buried pipelines subject to ground shaking, are investigated in this paper.

● **7.5-9** Beccali, G., Cosentino, P. and Trapani, S., **Seismic risk implications on the planning of solar energy systems,** *Sixth European Conference on Earthquake Engineering,*

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

Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. I, Paper 1-11, 1978, 79–86.

Central tower systems of solar energy plants located in highly seismic tropical and subtropical zones are analyzed from technical, social, and economic standpoints. The effects of earthquakes on the central towers are studied using a linear elastic modal analysis. The safety of such production systems and of other lifelines is discussed.

● **7.5-10** Mohraz, B. and Eskijian, M. L., **A study of earthquake response spectra for offshore platforms,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1257–1267.

This paper examines earthquake ground motion and spectral amplification for the design of offshore platforms. Since offshore platforms are typically flexible structures, sensitive to long periods of vibration, only records with long-period oscillation characteristics are included in this statistical study. The long-period oscillations of each record are examined by normalizing the Fourier amplitude spectral ordinates of the record, squaring the normalized ordinates, and then computing the area under the curve in the frequency range of interest. The areas provide a pseudo-measure of the power spectral density of the record in the specified frequency range. The influences of site geology and duration of strong motion on spectral amplification also are investigated and are compared with previous studies. Substantial differences exist between the results of this study and previous studies, particularly for spectra in the low-frequency range.

● **7.5-11** Bea, R. G. and Akky, M. R., **Seismic exposure and reliability considerations in offshore platform design,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1307–1328.

Decisions on earthquake ground motions appropriate for design should include consideration of the structural design process and of the projected performance of the structures to be designed. Seismic design parameters depend not only on geology and seismology, but also on the characteristics of the structure to be designed and on the degree of reliability desired. 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 (American Petroleum Inst.) normalized response spectra for design of offshore platforms are developed for 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.

● **7.5-12** Nair, D., Weidler, J. B. and Hayes, R. A., **Inelastic seismic design considerations for offshore platforms,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1383–1397.

The ability of offshore platforms to withstand extreme earthquakes is examined in terms of the inelastic energy absorption capacity. The important considerations in the design of platforms are shown to be the inelastic behavior of platform elements such as beam-columns and struts, the behavior of the panels, and the overall behavior of the platform itself. The intensity of the most extreme earthquake which the platform could withstand is estimated by equating the ultimate energy absorption capacity of the platform to the earthquake input energy. The postelastic behavior and the energy absorption capacity of platforms is exemplified by analyzing a typical frame. It is shown that properly designed conventional platforms can absorb substantial amounts of energy by inelastic action. By varying the local characteristics of the platform, it is demonstrated that, in addition to the overall energy absorption capacity, the local behavior of the platform also must be examined to arrive at meaningful results.

● **7.5-13** Kappler, H. and Schueller, G. I., **The influence of microzonation on the reliability-based design of offshore structures,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1399–1407.

A reliability concept is proposed in which the microzoning effect is introduced as a corrective factor to the probability distribution of the earthquake load intensity. The frequency of earthquake occurrence for sites under investigation is modeled by a Poisson process. In a numerical example, the concept is applied to a fixed (template) offshore platform located in a seismically active area at a water depth of 100 m. At such a depth, the governing design load type, either wave or earthquake, usually cannot be distinguished easily beforehand. It is shown that in areas where, according to the seismic mapping, the wave load is expected to be the governing design load, the earthquake load can yield lower reliability values because of the microzoning effect.

● **7.5-14** Watt, B. J. and Byrd, R. C., **Aseismic design considerations for concrete gravity platforms,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National

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Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1409–1431.

The dynamic response characteristics of concrete gravity platforms are contrasted with those of typical land-based structures and with the more conventional space-frame offshore platform concept. The nature and importance of fluid-structure interaction and soil-structure interaction are discussed in terms of experimental and analytical results. A design approach based on a two-level ground shaking criterion is suggested as the most sound procedure at this time. The special seismicity considerations relating to concrete gravity platforms are highlighted.

● **7.5-15** Iwan, W. D., **The earthquake design and analysis of equipment isolation systems,** *Earthquake Engineering and Structural Dynamics,* **6,** *6,* Nov.–Dec. 1978, 523–534.

A method is presented whereby the response spectrum may be used to predict the response of equipment mounted on an isolation system with nonlinear-motion-limiting constraints. The results of the approximate method are compared with results obtained by direct numerical integration for a representative piece of equipment.

● **7.5-16** Aggour, M. S., **Liquefaction induced by damaged buried piping,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 4, Paper 4-20, 1978, 147–154.

The extent of liquefaction that will develop as a result of damage to pipelines buried in granular soil is predicted by an approximate analytical method. The results determine the minimum safe spacing required between a structure and underground pipelines. The results can also be used for the determination of the minimum safe spacing required to separate two Category I pipelines buried in granular soil. The factors considered in the analysis are the diameter of the pipe, pressure in the pipe, and the depth of embedment. The results are presented in graphical form and show the effect of the above factors on the minimum safe spacing required.

● **7.5-17** Camfield, F. E., **Acceleration and impact of structures moved by tsunamis or flash floods,** *CETA 78-1,* Coastal Engineering Research Center, U.S. Army Corps of Engineers, Fort Belvoir, Virginia, Feb. 1978, 14.

Techniques are given for determining the velocity of a structure moved by a tsunami or a flash flood and the impact forces with another structure. Solutions can be obtained for velocity and impact force as a function of the initial distance between the structures and the velocity of the surging water.

● **7.5-18** Bea, R. G., **Earthquake criteria for platforms in the Gulf of Alaska,** *Journal of Petroleum Technology,* Mar. 1978, 325–340. (Presented at Eighth Annual Offshore Technology Conference, Houston, May 3–6, 1976.)

Depending primarily on location and type of soil-foundation condition, elastic design level earthquake motions producing peak effective ground velocities in the range of 50 to 70 cm/sec (20 to 28 in./sec) are indicated. To produce the desired level of loading and superstructure-foundation characteristics, a design wave height of approximately 120 ft is suggested along with the application of API RP 2A member-sizing guidelines. These results are applicable to the type of platform, design procedure, and analytical models used in this study. Design criteria are intended to be platform-system, strength-determining parameters. In an environment like the Gulf of Alaska, where there may be multiple environmental threats that produce loadings of comparable magnitudes, design criteria for one threat should not be selected without explicit consideration of other threats.

The potential force effects developed by severe ground motions on pile-supported platforms are very different from those caused by intense wave and current action. While loading patterns may be similar, one loading system fundamentally is force-limited (earthquakes) and the other is load-unlimited (wave and currents). As earthquake ground-motion intensity increases, the amount of transmitted load is limited by the ability of the foundation elements and soils to transmit that energy to the platform. In contrast, as wave-current action increases, the amount of imposed load essentially is unlimited.

Two fundamental efforts are identified that should be a focus of engineering research in this general area of technology. First, strong ground motions should be recorded at offshore sites in the Gulf of Alaska. Such records could be used to determine the applicability of attenuation and local soil-geology modulation relationships that describe the effects of distant earthquakes on a given location. No measurements have been made of strong ground motions offshore. Second, a realistic soil-pile superstructure interaction model applicable to moderate and intense levels of earthquake ground motions should be developed and calibrated. The simultaneous action of vertical and horizontal ground deformations along the entire length of piles is important because this action influences the energy conveyed to the superstructure. This in turn affects the induced inertial energy transferred from the superstructure to the piles and on to the soils. Only very simplified analytical models are available currently to assist the platform designer.

● **7.5-19** Shibata, H. and Tsuchiya, M., **Seismic reliability analysis of lifeline systems (1),** *Seisan-Kenkyu,* **30,** *7,* 1978, 13–15.

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

This paper deals with a methodology for seismic risk assessment of lifeline systems using reliability theory. The methodology is applied to case studies of a model lifeline system.

● 7.5-20 Tezcan, S., Muh, Y. and Civi, A., **Earthquake and wind analysis of Soma-B thermal power plant smoke stack,** *Internal Report 78-16E,* Earthquake Engineering Research Inst., Bogazici Univ., Istanbul, Jan. 30, 1978, 67.

● 7.5-21 Shinozuka, M., Takada, S. and Ishikawa, H., **Some aspects of seismic risk analysis of underground lifeline systems,** *Tech. Report No. PFR-CU-1,* Dept. of Civil Engineering and Engineering Mechanics, Columbia Univ., New York, Aug. 1978, 76. (Presented at the ASME Winter Annual Meeting, San Francisco, 1978.)

The current state-of-the-art of seismic risk analysis for underground lifeline systems, particularly for water transmission systems, is reviewed. This review analyzes the major causes of system damage and identifies seismic design decision analysis procedures unique to underground lifeline systems. A methodology for seismic risk analysis is developed and used to analyze a simplified version of the water transmission system in Los Angeles. In the analysis, a sample of damaged network systems is simulated by a Monte Carlo technique. Future research should include a topological analysis of such a sample of damaged systems to estimate the probability of an original system becoming unserviceable immediately following an earthquake of a given intensity. Such probability values are needed for design decision analysis.

● 7.5-22 Weidlinger, P. and Nelson, I., **Seismic analysis of pipelines with interference response spectra,** *Grant Report No. 7,* Weidlinger Assoc., New York, June 1978, 66.

Lifeline structures extending over long horizontal distances are affected by the noncoherent components of ground shaking. The response of interest is the relative displacement of adjacent points on the structure, instead of displacement relative to the ground. For this reason, the seismic analysis of lifelines requires techniques that are distinct from those used in the analysis of buildings. In this paper, the concept of the interference response spectrum is discussed. The spectrum presents the effects of the noncoherent free field on the dynamic response of lifeline structures quantitatively and in a unified form. Derivations, properties, and examples of interference response spectra are given.

● 7.5-23 Tamura, C. and Kawakami, H., **A method for evaluating the effect of earthquakes on a lifeline network system** (in Japanese), *Seisan-Kenkyu,* **30,** *7,* 1978, 44-47.

● 7.5-24 Shinozuka, M., Takada, S. and Kawakami, H., **Risk analysis of underground lifeline network systems,** *Technical Report CU-3,* Dept. of Civil Engineering and Engineering Mechanics, Columbia Univ., New York, Aug. 1977, 81.

A methodology of risk analysis for underground lifeline systems is developed and applied to the water transmission system in Tokyo. The topological characteristics of the system are analyzed to evaluate the possibility of unserviceability. Unserviceability occurs when water pipelines fail as a result of an earthquake. Whether a pipeline will fail depends upon the local ground conditions, the intensity of the earthquake, and the resisting capacity of the pipe structure. The local ground conditions, the intensity, and the occurrence of earthquakes are treated as random quantities and are considered along with characteristics unique to the Tokyo area. The probability of the unserviceability of the system when subjected to an earthquake of a specific intensity is evaluated.

● 7.5-25 Shibata, H., Shigeta, T. and Sone, A., **Seismic response and reliability of mechanical systems—effects of uncertainty of ground motions,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 133-146. (For a full bibliographic citation see Abstract No. 1.2-3.)

This paper deals with the uncertainty of the responses of structures to ground motions and the effect of this uncertainty on seismic-resistant design. The mechanical systems considered include the equipment, piping, and vessels found in nuclear power stations, petrochemical plants, and other industrial facilities. Because failure of such systems may be hazardous to the environment, the uncertainty of a future destructive earthquake must be evaluated to clarify the safety margin of the design. The uncertainty arises mainly because of the mechanism of fault movements and the stochastic nature of ground motions. Field observations augment the discussion.

● 7.5-26 Yuceoglu, U., Tedesco, J. W. and Driscoll, G. C., **Connections between equipment and structures subject to seismic loading—preliminary bibliography,** *Report 424.2,* Fritz Engineering Lab., Lehigh University, Bethlehem, Pennsylvania, Dec. 1977, 84.

Literature on earthquake and dynamic response, analysis, and design approaches for connections between equipment or machinery and structures are covered in this comprehensive bibliographic survey. The equipment discussed includes a wide range of units found in typical industrial installations such as materials processing plants, chemical plants, petroleum refineries, and fossil fuel power plants. Connections are treated as a component in an overall dynamic system including equipment or machinery, connections, structure, and foundations. The interactions of several components of the dynamic system are identified as the main problem in connection design.

Over 700 reference citations are presented including over 450 references on general analysis and design and over 250 references on equipment and machinery. Subdivisions within the sections on general analysis and design cover damage, codes, damping, details, and decision analysis. Among the topics covered under the category of equipment and machinery are generators, motors, pumps, pressure vessels, piping, tanks, stacks, electrical equipment, furnaces, bins, conveyor systems, mixers, precipitators, and cranes. The survey reveals that literature specifically treating connections is scarce, especially with regard to seismic problems. Design information must be gathered from related areas. A synthesis of this bibliography into a state-of-the-art report will be forthcoming.

● 7.5-27 Salvadori, M. G. and Singhal, A., **Strength characteristics of jointed water pipelines,** *IR-3*, Weidlinger Assoc., New York, July 1977, 84.

The present report has a threefold purpose: (1) to give a general description of a typical pipeline network, with particular emphasis on its geometric configuration and physical characteristics; (2) to describe the strength properties of typical pipeline materials and the materials used in their joints; to give a resume of test data on pipeline joints; and to correlate the test data with the results of elementary theory; (3) to describe standard pipeline design methods; to present typical pipeline modeling data; and to derive the needed typical entries for a static "failure matrix," which establishes failure characteristics for various types of pipelines, depending on their geometric configuration, their materials, the materials of their joints, and their support, operating, and loading conditions.

The report is the result of a survey of the literature on underground water pipes. Its purpose is to establish a static failure matrix methodology rather than present the application of such methodology to a complete set of pipeline types. Therefore, most of the data and examples are limited to cast-iron pipes of diameters between 4 in. and 36 in. under static conditions. The report also contains recommendations for additional tests on pipeline joints to complement the scant data available at present.

● 7.5-28 Shinozuka, M., Takada, S. and Ishikawa, H., **Seismic risk analysis of underground lifeline systems with the aid of damage probability matrix,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 179, Nov. 1978, 1423-1432. (Also published with appendixes as Technical Report PFR-CU2, Dept. of Civil Engineering, Columbia Univ., New York, Sept. 1978.)

A methodology for the seismic risk analysis is developed for a simplified version of the water transmission system in Los Angeles. In an example analysis, physically damaged network systems are simulated by means of a Monte Carlo technique. A topological analysis is performed to transform the transmission system into an SSP system associated with the defined serviceability. Each simulated damaged system is then uniquely represented by a correspondingly disrupted SSP system which can be used to evaluate more directly the impaired system serviceability.

● 7.5-29 Shiomi, S. and Tsutsumi, H., **A proposal for aseismic design of substation equipments comprising porcelain insulators and their foundations,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 153, Nov. 1978, 1217-1224.

This report discusses the seismic-resistant design of substation equipment of the insulator type and proposes a design method for this equipment. A formula is proposed for calculation of the natural frequency of the foundation-subgrade coupled system. A unique relationship is derived between the ratio f_1/f_0 and the amplification of the foundation response within the range of f_1/f_0 smaller than 0.5 (f_1 = natural frequency of the equipment, f_0 = natural frequency of the foundation-subgrade system). The propriety of the design method is discussed. The method uses three cycles of a sinusoidal wave having the same frequency as the resonant frequency of the equipment as input. A seismic-resistant design of the substation equipment and its foundation is proposed.

● 7.5-30 Yamada, Y. and Furukawa, K., **Application of optimization to earthquake resistant design of tower-pier system of long span suspension bridges** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 155, Nov. 1978, 1233-1240.

This paper presents the dynamic characteristics of a tower-pier system and investigates the changes in deterministic and probabilistic design approaches by applying optimization techniques to the earthquake-resistant design of tower-pier systems. An optimum earthquake design of the system also is presented. The system is assumed to have nine degrees-of-freedom. To simplify the problem, only two design variables are selected: the moment of inertia of the tower and the width of the pier. The damping constant is assumed to be 0.1 for the mode where the vibration of the pier is predominant and to be 0.02 for the vibration of the tower. For both coupling modes, 0.05 is assumed. The dynamic responses of the system are formulated in two ways: one is by a deterministic approach using a response spectrum and modal analysis; the other is probabilistic using power spectrum density, random vibration theory, and dynamic reliability analysis. In the case of optimization, the objective function is the cost of the system, and the constraints include stress of the tower, displacement of the pier top, buckling of the tower, and overturning of the pier. The objective function and constraints obtained in this way become nonlinear, and SUMT by Powell's direct search method without differential is employed as the optimization technique.

This study shows that the dynamic characteristics of the system are closely related to the coupling of modes resulting from the phenomena of accession and separation of the natural frequencies. Adjustment of the displacement constraint in the deterministic and probabilistic approaches is well satisfied, but the stress constraint is not satisfied for the excess of allowable stress by use of the deterministic approach. The importance of the displacement condition at a pier top must be discussed in more detail from the standpoint of structural safety in the small elastic modulus foundation range, and the need for earthquake-resistant design must be discussed for the dynamic response of a structure in the large elastic modulus foundation range.

● 7.5-31 Khosa, J. L., **Hazard free operation of hydro turbines**, *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies*, Japan Society of Mechanical Engineers, Tokyo [1977], 133–140.

The reliability of hydroturbines is well known. However, the choice of building materials and factors such as design, operation, and maintenance sometimes lead to problems resulting in serious damage to the generating equipment. Some of the real hazards associated with hydraulic turbines are cavitation, runaway speeds, surges, self-excited vibration, earthquakes, and dam failures. In the design of hydroturbines, stress levels, weldability, fatigue, controls, etc., are considered. The role of standardization in producing reliable equipment is highlighted. A number of case histories are described and remedial measures taken to prevent repetition of problems which have occurred are discussed. The development of hydroturbines for high-capacity installations is also examined.

● 7.5-32 Nair, V. V. D., **Aseismic design of offshore platforms**, *Earthquake Engineering and Soil Dynamics*, Vol. II, 660–684. (For a full bibliographic citation, see Abstract No. 1.2-11.)

In this paper, a state-of-the-art procedure for the earthquake-resistant design of offshore platforms is presented. The dual design philosophy is reviewed and it is pointed out that, in certain cases, it is prudent to distinguish between the drilling and production phases in formulating the design criteria. The interaction of the soil-pile system with the platform and the effects of fluid-structure interaction are discussed. Engineering procedures to account for these effects in design also are reviewed. Concepts and guidelines for the design of offshore platforms are presented. Procedures to develop structural and foundation configurations as well as factors to be considered in the selection of preliminary member sizes are discussed. The parameters which will have a major influence on the dynamic behavior of the platform are identified and discussed. The dynamic behavior of offshore platforms is illustrated by presenting the analysis of a jacket in 500 ft of water. Response of the structure to two types of response spectra is evaluated. Results presented include natural periods, participation factors, lateral force distributions, deflections, and mudline forces. Finally, areas are identified in which additional research is needed to improve existing design procedures.

● 7.5-33 Kajimura, Y. and Shiraki, K., **Study on aseismic strength of boiler frame structure based on the investigation of its damage by Niigata earthquake**, *HOPE International JSME Symposium–Hazard-free Operation against Potential Emergencies*, Japan Society of Mechanical Engineers, Tokyo [1977], 181–188.

The earthquake that hit the Niigata district in June 1964 caused widespread destruction. The Niigata Power Station Unit No. 1 boiler frame operated by the Tohoku Electric Power Co., Inc., was one of the facilities that suffered damage from the earthquake, although the damages were slight. A post-earthquake damage survey disclosed that the main structure remained intact, although a subordinate structure was damaged. This paper, which was prepared as a result of the investigation, analyzes the response behavior of the boiler frame and emphasizes its ability to withstand earthquake motion.

● 7.5-34 **Seismic design for police and fire stations**, AIA Research Corp., Washington, D.C., 305. (Accompanied by *Management needs summary: seismic design for police & fire stations*, PTI-78/005, Public Technology, Inc., Washington, D.C., 1978, 12.)

This report discusses issues that should be considered in the seismic design of police and fire stations in areas susceptible to earthquakes. The contents include the following: Introduction, Police and Fire Stations, Emergency Operating Centers, Seismic Renovation, Multi-Hazard Design, and References.

● 7.5-35 Kelly, J. M. and Sackman, J. L., **Response spectra design methods for tuned equipment-structure systems**, *Journal of Sound and Vibration*, 59, 2, July 22, 1978, 171–179.

A description is given of a design method that allows response spectra to be used to estimate maximum displacements and accelerations in equipment-structure systems. The system involves light equipment tuned to a natural frequency of the structure. The solution is developed by using transform methods, residue theory, and asymptotic analysis. A very simple result is obtained which should be of value to designers of equipment, equipment mountings, and nonstructural components in structures subject to

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

dynamic loading. The simple nature of the result is explained by a direct physical interpretation of the response.

● 7.5-36 Kamil, H., **Nonlinear design of offshore structures under extreme loading conditions,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3047, 1978, 39–48.

A procedure is presented for the nonlinear design of offshore structures subjected to extreme loads such as strong-motion earthquakes. It is proposed that the design be based on the safety level earthquake (SLE) and be checked for the operating level earthquake (OLE). A reduced inelastic response spectrum should be used for the SLE. It is recommended that the preliminary design be obtained using a response spectrum approach. Nonlinear analyses then should be performed using one or more artificial time histories of ground motion compatible with the inelastic spectrum. The preliminary design could be modified as necessary to obtain the final design. The reliability of the final design could then be estimated using a deterministic-cum-probabilistic procedure.

● 7.5-37 Moses, F. and Stahl, B., **Reliability analysis format for offshore structures,** *Offshore Technology Conference—1978, Proceedings of Tenth Annual,* Offshore Technology Conference, Dallas, Texas, Vol. I, OTC 3046, 1978, 29–38.

An incremental loading approach to structural reliability analysis is presented and illustrated. The structure is progressively "unzipped," as successive members reach their capacity, until overall structural collapse occurs. An inherent advantage of this approach is that the variance of structural capacity is extracted in addition to the mean value, with a minimum of computational effort. The method accounts for different types of member behavior such as brittleness and ductility, different structural arrangements such as members in parallel and series, and statistical and mechanical correlation between structural elements.

● 7.5-38 Kelly, J. M. and Chitty, D. E., **Testing of a wind restraint for aseismic base isolation,** *UCB/EERC-78/20,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1978, 46. (NTIS Accession No. PB 292 833)

Base isolation has been proposed as an economical approach to seismic-resistant design for many types of buildings and structural systems. In general, the base of a structure is isolated when a support system with extremely low horizontal stiffness limits the transmittal of horizontal shear from the ground to the structure. The displacement of such a structure under wind loading will, however, be excessive, because the horizontal stiffness of the support system is so low. The horizontal deflection of a building with an isolated natural frequency of 0.5 Hz would, for example, be four inches for a wind load of one-tenth the weight of the building. While such a horizontal deflection would not be acceptable, a base isolation system could be equipped with a mechanical fuse which would be sufficiently strong to resist wind loading, but which would fracture during an earthquake, leaving the building free on the isolation system.

This report describes an extensive series of shaking table tests of such a device. The wind restraint consisted of a notched shear pin. Several shear pins were tested in conjunction with a natural rubber isolation system placed beneath a three-story, 40,000 lb steel frame model structure. Pins with breaking forces ranging from 3% to 20% of the weight of the model were tested. The model structure was subjected to various peak accelerations of three earthquake inputs. The shear pins fractured rapidly and cleanly. The breaking force for each pin was reasonably predictable. Although higher mode accelerations were induced in the model structure when the pins broke, these disappeared rapidly. The design of a shear pin mechanical fuse system for a full-scale structure is discussed in light of the experimental results described.

● 7.5-39 Sackman, J. L. and Kelly, J. M., **Rational design methods for light equipment in structures subjected to ground motion,** *UCB/EERC-78/19,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1978, 72. (NTIS Accession No. PB 292 357)

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 the information available to the designer is a design spectrum for the ground motion, the fixed-base modal properties of the structure, and the 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 has also been 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

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of the maximum equipment response to be obtained without the necessity of computing time histories, as is required by the conventional floor spectrum method.

● 7.5-40 Bhatti, M. A., Pister, K. S. and Polak, E., **Optimal design of an earthquake isolation system,** *UCB/EERC-78/22,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1978, 116. (NTIS Accession No. PB 294 735)

An optimal design of an earthquake isolation system, consisting of natural rubber bearings and special nonlinear energy-absorbing devices, is presented. An algorithm for efficient analysis of structural response, based upon the Newmark and Runge-Kutta methods with optional Newton-Raphson iteration, is given. The optimal design problem, incorporating this simulation algorithm, is formulated as a mathematical programming problem with time-dependent constraints and is solved using a feasible directions algorithm. Several numerical examples are presented, in which it is demonstrated that a properly designed isolation system can substantially reduce structural damage for a class of potential earthquakes.

● 7.5-41 Hognestad, E., chmn., ACI Committee 357, **Guide for the design and construction of fixed offshore concrete structures,** *Journal of the American Concrete Institute,* **75,** *12,* Title No. 75-72, Dec. 1978, 684-709.

The report provides a guide for the design and construction of fixed reinforced and/or prestressed concrete structures for use in a marine environment. Only fixed structures which are founded on the seabed and obtain their stability from the vertical forces of gravity are covered. The following topics are included: materials and durability; dead, deformation, live, environmental, and accidental loads; design and analysis; foundations; construction and installation; and inspection and repair. Two appendixes discuss environmental loads, such as wave, wind, and ice loads in detail, and the design of offshore concrete structures for earthquake resistance.

● 7.5-42 Howell, G. C. and Doyle, W. S., **Dynamic programming and direct iteration for the optimum design of skeletal towers,** *Computers & Structures,* 9, *6,* Dec. 1978, 621-627.

A computer technique is proposed for a simple, practical method of automatically designing tower structures. Dynamic programming is used to find the optimum geometric configuration of the structural members, while the member sizes are proportioned by direct iteration. Tower structures are particularly suited to this method of automatic design since the speed of the analysis and design depends primarily upon substructuring. Substructuring of towers is comparatively simple because interaction between adjacent substructures can be simulated with reasonable accuracy. Typical examples are presented.

7.5-43 Gero, J. S. and Dudnik, E. E., **Uncertainty and the design of building subsystems—a dynamic programming approach,** *Building and Environment,* 13, *3,* 1978, 147-152.

This paper discusses the general problem of designing building subsystems which include probabilistic demands, thus producing a stochastic problem. This kind of problem, if linear, can be readily solved using classical stochastic linear programming. It is shown that the problem may be formulated as a stochastic dynamic program. A problem of designing the HVAC subsystem is formulated and solved as a dynamic program. Comparisons are made between the two methods. It is shown that dynamic programming is the more powerful method both in terms of obtaining the solution and its post-optimality analysis. It is suggested that dynamic programming is a suitable technique for a wide range of building and architectural design problems.

● 7.5-44 **World dams today, '77,** Japan Dam Foundation, Tokyo, 1977, 576.

This publication contains data on 138 dams in 48 countries and includes an index of the dams, projects, reservoirs, lakes, and power plants described. The following papers are relevant to earthquake engineering. None of these papers is abstracted in this volume of the *AJEE.*

Arenal Dam—a major dam on Costa Rica's Arenal River, Wahler, W. A.—*The Sabana Yegua Dam in Dominican Republic,* Visentini, G. and Guzman R., L.—*Mornos Dam, Greece—dam construction in sliding endangered flysch and karstified limestone,* Schewe, L. D.—*Recent high dams in India,* Murthy, Y. K.—*Unusual repair works on the upstream face of a dam,* Vecellio, T. and de Pellegrin, P.—*Design and construction features of Iwaya Dam,* Morikawa, T.—*New advances in seismic design of concrete dams,* Stamm, G. C.—*Live Oak Reservoir,* Wahler, W. A.—*The Los Angeles Reservoir Project,* Lund, L. V.—*Pyramid Dam,* Lawder, J. H.—*Large dams of some hydroelectric stations in the USSR,* Borovoi, A. *et al.*

● 7.5-45 Htin, K., **Design of prestressed precast girder bridge and study of free vibration characteristic of high pier,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 171-192.

The objective of this study is to represent a complete design for a typical prestressed, pretensioned concrete bridge superstructure and to study the free vibration characteristics for a tall pier. Design seismic coefficients obtained by use of a modified design seismic coefficient method and from free vibration analysis are compared.

● **7.5-46** Priestley, M. J. N. and Stockwell, M. J., **Seismic design of South Brighton Bridge—a decision against mechanical energy dissipators,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *2,* June 1978, 110–120.

The seismic design of a proposed bridge, located upstream from the junction of the Avon River with the Christchurch estuary in New Zealand, is discussed. The initial design was based on supporting the superstructure on elastomeric bearing pads and steel-cantilever dampers. Dynamic analyses showed that the dampers were relatively ineffective and that the seismic response was dictated by the characteristics of the bearing pads. The final design, based on a conventional ductile approach, is found to be more economical without significantly increasing the seismic risk. It is shown that the decision to use a design incorporating mechanical energy dissipators as opposed to a monolithic pier/superstructure design will not necessarily result in a reduction in seismic response.

● **7.5-47** McGavin, G. L., **Seismic qualification of nonstructural equipment in essential facilities,** California State Polytechnic Univ., Pomona, 1978, 268.

Facilities such as hospitals and police stations are necessary to serve the public after a severe earthquake. Experience such as that obtained in the 1971 San Fernando earthquake shows that the nonstructural equipment required for the operation of essential facilities is commonly unable to perform its designated function in the aftermath. Equipment failure is a serious problem. Upgrading of existing seismic codes and specifications is a continuous process. The codes for nonstructural equipment, however, ignore the dynamic nature of earthquakes as well as operational requirements of equipment during and after a significant earthquake. This paper discusses the types of nonstructural equipment required for essential facility operation (e.g., emergency power supplies, life support systems, communication systems, etc.), examines existing seismic codes, examines typical existing equipment product lines, suggests revisions to current legislation, and suggests approaches that design teams and facility owners may take in order to increase the operability of essential facilities after a severe earthquake.

● **7.5-48** O'Rourke, M. J. and Wang, L. R.-L., **Seismic shaking of buried pipelines,** *Seismic Vulnerability, Behavior and Design of Underground Piping Systems, Technical Report 6,* Dept. of Civil Engineering, Rensselaer Polytechnic Inst., Troy, New York, Aug. 1978, 22. (Presented at American Society of Civil Engineers Convention, Chicago, Oct. 1978.)

The problem of designing buried pipelines for wave propagation effects caused by earthquakes is studied. The response of a buried pipeline to traveling seismic waves is investigated by assuming that the buried pipeline and the soil move together. Using ground displacement time histories recorded during the 1971 San Fernando earthquake, the effect of changes in the shape of the traveling seismic waves as they traverse the pipeline is found to be significant for certain cases. Presently available simplified procedures for design assume that the shape of the traveling seismic waves remains unchanged. No significant difference was found between the maximum velocity and acceleration of the radial and tangential components of ground motion in the near field. Current design codes for water and sewer systems do not take seismic loading into account. A procedure for including seismically induced strains into the present static design approach also is presented.

● **7.5-49** Kelly, T. E., **Floor response of yielding structures,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **11,** *4,* Dec. 1978, 255–272.

The New Zealand loading code, NZS 4203:1976, specifies design forces for nonstructural components determined on the assumption that maximum floor accelerations are related to the yield level for ordinary structures. The code committee was aware that there was a scarcity of factual information on the subject and suggested that studies be carried out. The work described in this paper is aimed at investigating floor motions in buildings responding elastically and inelastically to earthquake motions to obtain a basis for the design of nonstructural components and also ancillary services.

Twelve structures ranging in height from one to eight stories and of varying structural type were analyzed by using a dynamic computer program for elastic response and for two different levels of structural yield strength. Time histories of floor acceleration were obtained at each floor level and, from these, the maximum absolute values were obtained. To derive loadings on flexible and flexibly mounted components, response spectra were calculated for upper floors and the amplification factors relating floor spectra to ground spectra were derived. The basic dynamic parameters used were the El Centro 1940 N-S earthquake record, with constant damping and material strain-hardening ratios. The effect of variations in these parameters was studied for a limited number of the structures.

From results obtained, tentative equations have been formulated for the design of both rigid and flexible components. For flexible components, the floor amplification

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function was found to be very complex and allowance must be made for uncertainties in dynamic parameters, such as component damping, and for factors such as higher mode effects which influence the response.

● 7.5-50 Yancey, C. W. C. and Camacho, A. A., **Aseismic design of building service systems: the state-of-the-art,** *NBS Technical Note 970,* Center for Building Technology, U.S. National Bureau of Standards, Washington, D.C., Sept. 1978, 78.

A search for information was conducted to define the state-of-the-art of earthquake-resistant design of building service systems and to identify areas of needed research. The study focused primarily on service systems essential to the continuous operation of hospital facilities in post-earthquake periods. A review of the literature pertaining to seismic performance of nonstructural systems is presented. An evaluation of code and standard regulations applicable to the earthquake-resistant design of service system components is also presented. Information obtained from direct contact with several federal agencies, the State of California, and practicing architects and engineers is summarized. The findings from a field visit to two hospitals currently under construction in earthquake-prone areas are reported. Deficiencies in current design/evaluation practice are identified, and recommendations for research are presented.

● 7.5-51 Bayulke, N., **Architectural design from a seismic viewpoint** (Deprem acisindan mimari tasarim, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **6**, *22,* July 1978, 43-60.

In this paper, the effects of architectural design features on the structural design and earthquake response of buildings are pointed out. Some examples of architectural features which cause unfavorable behavior of buildings during earthquakes are given and it is suggested that the architects should pay more attention to the probable effects of their architectural design on the seismic behavior of structures.

● 7.5-52 **Design of arch dams,** *Water Resources Technical Publication,* U.S. Bureau of Reclamation, Denver, Colorado, 1977, 882.

This manual presents instructions, examples, procedures, and standards for the design of concrete arch dams. It serves as a guide to sound engineering practices in the design of concrete arch dams, and provides the technically trained, qualified design engineer with specialized and technical information that can be readily used in the design of such a dam.

● 7.5-53 **Design of small dams,** rev. ed., *Water Resources Technical Publication,* U.S. Bureau of Reclamation, Denver, Colorado, 1977, 816.

7.6 Design and Construction of Foundations, Piles and Retaining Walls

● 7.6-1 Shioi, Y. *et al.,* **Recent earthquake resistant design methods for different types of foundations in Japan,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. II, 1978, 1001-1011.

To determine the methods used in Japan to design bridge foundations, 31 long-span bridges are studied. The foundations are classified into four types: spread foundations, piles, caissons, and multicolumn foundations. For each type, the design methods and the methods for modeling soil-foundation interaction effects are surveyed.

● 7.6-2 Chakrabarti, S. *et al.,* **Seismic design of retaining walls and cellular cofferdams,** *Earthquake Engineering and Soil Dynamics,* Vol. I, 325-341. (For a full bibliographic citation, see Abstract No. 1.2-11.)

Gravity-type cellular cofferdams are widely used as waterfront retaining structures. Static design of these structures generally considers several modes of static failure. The experience gained from post-construction observation of cofferdam behavior has greatly enhanced the postulation of admissible failure mechanisms that should be considered in design. Because static methods of cofferdam design have become somewhat standardized and have been verified through observations of performance, a promising approach to the seismic design of such structures is centered about the development of consistent pseudo-static failure mechanisms. This paper illustrates such extensions of the static design techniques and compares the factors of safety obtained from static and pseudo-static (seismic) analyses. Certain design criteria which have been modified to account for dynamic action are explained. Local soil, rock, and hydrostatic conditions, as well as liquefaction potential and hydrodynamic forces, are considered.

The method of analysis admits various assumptions that are based on the static failure modes of the analytical models; for example, the postulated sliding failure condition assumes an inflexible rigid body-type of behavior, while Cumming's method of horizontal shear considers the structure to be flexible and the soil to be capable of developing failure planes. By extending these postulated failure modes for the dynamic analysis, the same modeling assumptions are admitted for the pseudo-static case. The methodology proposed is suggested as a means of conservatively performing design checks and using simplified procedures, and not as a replacement for a dynamic, state-of-stress response analysis.

● 7.6-3 Mamoko, M. P., **Some considerations in the earthquake-resistant design of retaining walls,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **14,** Dec. 1978, 357–366.

This paper discusses universally accepted current design methods for retaining walls. The limitations and inadequacies of the methods are compared and suggestions for improvements are made.

7.7 Design and Construction of Soil and Rock Structures

● 7.7-1 Koh, S. L. and Chen, W.-F., **The prevention and control of landslides,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 325–337. (For a full bibliographic citation see Abstract No. 1.2–3.)

Landslides and slope failures are triggered by a variety of causes, including severe rainstorms and earthquakes, as well as such disturbances as those caused by construction works and explosions. However, the basic concept underlying the instability of a mass of soil in its simplest form is applicable to these different situations. This concept, the mechanics of landslides, is briefly discussed. Measures to minimize the occurrence of these hazards are considered. A review is presented of the remedial measures now in use to correct the effects of a landslide or to arrest impending slope failure.

● 7.7-2 Kawasaki, T. *et al.,* **Seismic response analysis of composite ground treated by deep chemical mixing stabilization method: part 1-an analytical method** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 97, Nov. 1978, 769–776.

This paper describes a method of seismic response analysis of a harbor structure built on composite ground of soft, thick alluvial clayey deposits. The quasi-nonlinear characteristics of surrounding soils and the quasi-three-dimensional effect of geometrical expansion are considered. A practical technique is used to condense the degrees-of-freedom in the analysis. It is reasonable to assume that a natural soft deposit, when located sufficiently far from harbor structures supported by a composite ground, behaves in a manner not influenced by the structures. To take this effect into account, the analytical method causes the motion at the side boundary mass points to coincide with the responses that have previously been obtained by means of one-dimensional quasi-nonlinear wave propagation theory for horizontally multilayered surrounding soft deposits. The equation of motion for the reduced analytical model becomes a multi-input problem. The velocity and displacement at each boundary mass point are calculated by using the fast Fourier transform method with a band-pass filter. It was verified by the results of analyses on simple models that this analytical method is a useful and reliable method.

● 7.7-3 Kawasaki, T. *et al.,* **Seismic response analysis of composite ground treated by deep chemical mixing stabilization method: part 2-results of analysis** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 98, Nov. 1978, 777–784.

Soft marine clay deposits stabilized using chemicals have been recently recognized as one type of foundation to support harbor structures. The stabilized ground, surrounded by soft marine clay, consists of treated soil walls and untreated soil and is called a composite ground. The static stability problems of such a composite ground are usually treated based on the Design Manual of Harbor Structures in Japan. However, there are some problems when applying the seismic coefficient method to seismic-resistant design. The object of this paper is to study the dynamic behavior and stability of composite ground by carrying out seismic response analysis in order to aid in the seismic-resistant design of such a ground. The unique feature of the method used in the analysis is that the nonlinearity of the surrounding ground is taken into account by evaluating the nonlinear dynamic soil properties. Effects of both the exciting direction (normal and parallel to the caisson) and the motion (wave shape and maximum acceleration) of the input earthquake excitations are considered.

A summary of the analytical results for some models provides the following conclusions: (1) The continuously broadening effects and nonlinear stress-strain behavior of the soft marine clay deposits around the composite ground are taken into account in the analysis by introducing the excitations on the side boundary of the model and by determining the dynamic properties of soil based on Ramberg-Osgood curves. Dynamic behavior of the composite ground during earthquakes can be estimated for design purposes by using a quasi-three-dimensional model with reduced degrees-of-freedom. (2) The results obtained from case studies showed that (a) the untreated soil between the walls consisting of treated soil showed approximately the same response as that of the treated soil, (b) the treated soil showed less acceleration response than that of surrounding soft ground, and (c) no safety factor less than unity could be found in the stabilized ground, although an area in the surrounding ground with a safety factor less than unity will develop as the magnitudes of input earthquake excitations increase.

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● 7.7-4 Erguvanli, A., **Aspects of aseismic design procedures for fill dams**, *Bulletin of the International Institute of Seismology and Earthquake Engineering*, **16**, 1978, 25–38.

Procedures for the earthquake-resistant design of slopes and fill dams are presented in order to compare the limitations and insufficiencies of the existing analysis methods. The seismic coefficient method and dynamic analysis, together with large model tests, yield reliable results. However, it is suggested that further refinements and development of new techniques are required for practical design purposes.

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8. Earthquake Effects

8.1 General

● 8.1-1 Algermissen, S. T. and Steinbrugge, K. V., **Earthquake losses to buildings in the San Francisco Bay area,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. I, 1978, 291–302.

Losses in the San Francisco Bay area are simulated for five broad classes of buildings which include the majority of building types found in the area. Losses are expressed as average percentages of the total actual cash value required to fully repair, in kind, any building in a particular class. The inventory of dwellings was obtained from census data; the inventory for buildings other than dwellings was derived from land-use classification in the area supplemented by minimal field work. Long-term annual losses for the various building classes range from 0.1 to 1.6%. For a large earthquake on the San Andreas fault, the range in percent loss is about 5.0 to 25%, depending on the building class. The 1970 value of dwellings in the nine-county Bay area was $30.289 billion. Annual average losses to dwellings is estimated at $271 per dwelling. The average loss per dwelling as a result of a large earthquake on the San Andreas fault would be about $1,355; the total loss (1970), about $1.5 billion.

● 8.1-2 Oliveira, C. S., **Probability damage matrices based on continuous state variables,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-09, 1978, 67–74.

Data from recent earthquakes has shown that there is a functional random relation between the degree of damage or damage ratio and the intensity of shaking. The conditional probability distribution function of the damage random variable associated with different discrete intensities of shaking led to the so-called probability damage matrix. Damage has been considered as a random variable (RV) of the discrete type with sample space defined by a finite number of states of damage. To study the sensitivity of the parameters influencing the general behavior of the damage RV, a continuous formulation was developed considering the following assumptions: (i) damage is a continuous monotonic increasing function of structural response; (ii) the dispersion of building characteristics is considered through two joined RVs, the starting threshold of damage, and the final threshold of damage, (iii) the functional relation referred to in (i) is deterministic and of a power type.

● 8.1-3 Kuribayashi, E. and Tazaki, T., **An evaluation study on the distribution of property losses caused by earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction–Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1499–1510.

A statistical model is employed to evaluate the property losses caused by earthquakes at various kinds of facilities. The property loss was determined by multiplying the value of existing property in the seismic area with the loss ratio for that area. The loss ratio was represented as a function of the magnitude of an earthquake, epicentral distance, and subground condition. Subground condition was divided into two categories: alluvial, and diluvial and Tertiary. The existing property was estimated using data from the National Wealth Survey of Japan. The data for 18 earthquakes which have occurred in Japan since 1923 were used in the analysis.

● 8.1-4 Takizawa, H., **Characterization of extreme earthquake motions by destructive capability to R/C buildings,** *Proceedings of the Fifth Japan Earthquake Engineering*

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Symposium-1978, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 108, Nov. 1978, 857–864.

Quantitative examinations are made of the capability of extreme ground shaking for causing damage to and the collapse of R/C buildings. The study illustrates important trends in the gross mechanics of structural failure and provides a destructive rating of strong-motion records. The ensemble of excitations examined in this study covers many accelerograms with high peak accelerations. This includes impulsive type shaking featured by markedly high amplitude, as well as the more typical records of longer duration. For purposes of specifying the variations in the fundamental properties of the records, a three-parameter measure in terms of amplitude, duration, and frequency content is introduced on the basis of the time- and frequency-domain distributions of total oscillational energy. The structural models are based on the previously developed "equivalent" formulation of the overall behavior of completely nonlinear R/C buildings. An instance of overall failure is employed as the reference system for response analyses and it is characterized by the restoring force properties that are ideally ductile up to the ultimate destabilization caused by the effects of gravity. The destructive potential of the derived motions is then scaled by use of "damage and collapse accelerations," and the differing correlations of the motions with the three-parameter measure are emphasized. By comparison with the reference case, the influences of ductility deterioration and localized failure, which can be significant factors in reducing structural capacity, are also investigated.

● 8.1-5 Mochizuki, T., Miyano, M. and Matsuda, I., **On distribution of the damaged wooden houses owing to earthquakes-relationships among magnitude of earthquake, type of earthquake fault, epicentral distance, land form and ratio of completely collapsed houses** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 175, Nov. 1978, 1391–1398.

If an earthquake fault is a reverse one with a low dip angle, the distribution patterns of seismic intensity and damaged wooden houses are very different on either side of the fault line. For an earthquake fault with a high dip angle, for example about 90 degrees, the distribution patterns of damaged wooden houses and seismic intensity are not very different on either side of the fault line. When an earthquake generated by a fault with a low dip angle has about the same magnitude as that generated by a fault with a high dip angle, the damaged area caused by the former is likely to be much larger. The farthermost limit of an area where some wooden houses might totally collapse during a magnitude 7.0 earthquake is located within a distance of 15 km from a fault. For earthquakes with magnitudes of 7.9 or 8.0, the limit varies greatly. Except for an area along an earthquake fault, the damage ratio of wooden houses in alluvial lowlands is generally higher than the ratio in mountainous areas. In cases where damage is restricted to vibration resulting from a large, distant earthquake, the ratio of completely collapsed wooden houses can be clearly correlated to the thickness of the alluvial deposits.

● 8.1-6 Kuribayashi, E., Hadate, T. and Saeki, M., **Effects of subground conditions to earthquake damage ratios of wooden dwelling houses in the Fukui earthquake of 1948** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 174, Nov. 1978, 1383–1390.

This paper discusses the relationship between earthquake damage ratios for wooden houses and ground types in the 1948 Fukui earthquake. Research has indicated that wooden houses built on soft ground suffer greater damage than those built on firmer ground. The study makes the following conclusions: (1) the damage ratio is larger in areas of alluvial layers than in areas of bedrock and diluvial layers; (2) the damage ratio is larger in deep deposits of clayey soil; and (3) the damage ratio attenuation depends on the distances from the epicenter and the fault lines, and the rate of attenuation is larger in the area of bedrock than other soil types.

● 8.1-7 Liao, Z.-P., Yang, P.-P. and Yuan, Y.-F., **Feedback effect of low-rise buildings on vertical earthquake ground motion and application of transmitting boundaries for transient wave analysis**, Inst. of Engineering Mechanics, Academia Sinica, Harbin, China, Oct. 1978, 23.

Vertical earthquake ground motion is one of the important factors causing damage to buildings in a meizoseismal area. The vertical motion of a building during an earthquake and the feedback effect on the ground motion is of interest in engineering problems. Ordinary lowrise buildings, the heights of which are far less than the seismic wavelengths and which also have greater vertical rigidity, can be analyzed by use of a model of a rigid body bonded to the surface of an elastic halfspace. The model is also used to study the upthrow of a small object from the ground during an earthquake. These problems are studied by means of the finite difference method. The transient features of earthquake ground motion, the weight and dimensions of the building, and the physical properties of the foundation material are considered. The primary findings are that the feedback effect of ordinary buildings on vertical earthquake ground motion is comparatively small and can be neglected in practice, and that the upthrow of a small compact mass from the ground during an earthquake usually can be considered as an indication of the ground acceleration exceeding that of gravity.

Along with the finite difference calculation, simple transmitting boundaries for body waves and Rayleigh waves are devised. According to the numerical results of the

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scattering waves caused by the rigid body, these artificial boundaries have an excellent capacity for transmitting near-field transient elastic waves. Computer storage and computing time are much reduced by use of this method.

8.2 Studies of Specific Earthquakes

● 8.2-1 Tezcan, S. S., Yerlici, V. and Durgunoglu, H. T., **A reconnaissance report for the Romanian earthquake of 4 March 1977,** *Earthquake Engineering and Structural Dynamics,* **6,** *4,* July-Aug. 1978, 397–421.

The engineering aspects of the March 4, 1977, Romanian earthquake are presented. They are based upon a field investigation conducted by the authors in Bucharest and in southern Romania in collaboration with members of the Building Research Inst. of Romania during March 25–31, 1977. This report covers general observations, data, and analyses of the character of the earthquake. Also discussed are structural damage caused by the earthquake, structural performance, and relief operations.

● 8.2-2 Polyakov, S. V. *et al.*, **Analysis of consequences of the Carpathian earthquake on March 4, 1977 on the territory of the Moldavian Soviet Socialist Republic,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-07, 1978, 47–58.

On Mar. 4, 1977, a destructive earthquake with an epicenter near Vrancea occurred. The depth of the focus is estimated to be 90 to 110 km; the average magnitude is 7.2, according to scores of instrumentation records from Europe. The ground motions were felt in many European countries, and in some countries (Romania, Bulgaria, Yugoslavia, and the U.S.S.R.) a number of buildings were damaged and collapsed. In the territory of Moldavia, according to an engineering analysis of building damage, the intensity of the earthquake was evaluated as follows: Tiraspol, Kotovsk, Bendery—about 6; Kishinev—somewhat higher than 6; Leovo, Kagul, Vulkaneshty—about 7, while the seismicity in the above-mentioned localities was lower by one point.

● 8.2-3 Gurpinar, A. *et al.*, **The November 24, 1976 Caldiran earthquake,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-05, 1978, 33–40.

A severe earthquake shook eastern Turkey on Nov. 24, 1976. The earthquake had an epicentral intensity of I_o = IX on the MSK scale and caused large-scale destruction of inadequately constructed local dwellings. This report was prepared by a joint team of engineers and seismologists and encompasses a description of the event as well as the structural damage it caused.

● 8.2-4 Demir, H., **The Lice, Turkey earthquake of September 6, 1975,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-04, 1978, 23–32.

On Sept. 6, 1975, an earthquake of magnitude 6.8 with epicenter near Lice in the Diyarbakir Province of eastern Anatolia, Turkey, occurred. The loss of lives was 2385 and the number of buildings destroyed or damaged beyond repair were 8159. In this paper, based on a site investigation conducted immediately after the earthquake, damages to buildings are described. Reasons for damage and lessons learned or relearned are cited.

● 8.2-5 Sandi, H., Serbanescu, G. and Zorapapel, T., **Lessons from the Romania, 4 March 1977, earthquake,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 6(a), 1978, 1–25.

After a brief introduction concerned with the social, economic, and technical size of the Romania Mar. 4, 1977, earthquake, data on the ground motion and the behavior of structures are presented. The ground motion characteristics are discussed on the basis of instrumental information and on extensive surveys carried out by several large teams. The behavior of structures is discussed after an attempt to classify the problem. Special attention is paid to buildings and industrial structures and the most significant conclusions on structural behavior and building policies are summarized. The final part is devoted to some important aspects of development policies of engineering seismology and earthquake engineering.

● 8.2-6 Weber, Jr., F. H. and Kiessling, E. W., **Historic earthquakes: effects in Ventura County,** *California Geology,* **31,** *5,* May 1978, 103–107.

● 8.2-7 Moinfar, A. A., **The Romania earthquake of March 1977** (in Persian with English summary), 77, Technical Research & Standard Bureau, Iran Plan and Budget Organization, Tehran, Jan. 1978, 65.

On Mar. 4, 1977, a strong earthquake of magnitude 7.2 occurred in Romania. The shock was felt in many European cities. The earthquake's epicenter was in the Vrancea region of the Carpathian Mountains about 160 km northeast of Bucharest. Its focal depth was about 91 km, according to the United States Geological Survey. The causes of structural damage and collapse resulting from the Romanian earthquake are reviewed. Diagrams, charts, and photographs are presented.

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● 8.2-8 Thenhaus, P. C., **A study of the October 12, 1877 Oregon earthquakes,** *Open-File Report 78-234,* U.S. Geological Survey, n.p., 1978, 14.

Historic accounts indicate that two earthquakes occurred in northern Oregon on Oct. 12, 1877. The first event, of modified Mercalli intensity III, took place at Cascades, Oregon (now Cascade Locks) at approximately 9:00 a.m. The second earthquake, of modified Mercalli intensity VII, occurred in Portland, Oregon, at approximately 1:53 p.m.

● 8.2-9 Kubo, K. *et al.*, **Miyagi-ken-oki earthquake of June 12, 1978—preliminary report** (in Japanese), *Seisan-Kenkyu,* 30, *11,* 1978, 1-25.

● 8.2-10 Kobayashi, H. *et al.*, **A report on the Miyagiken-oki, Japan, earthquake of June 12, 1978,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 587-614.

On June 12, 1978, a severe earthquake occurred in northeastern Japan. Twenty-seven persons were killed, and more than 110,000 houses were damaged. The paper is in four parts. Part I describes strong ground motion and seismic microzoning. Part II discusses geotechnical aspects of the damage caused by the earthquake. Parts III and IV are concerned with damage to lifeline and utility systems.

● 8.2-11 Hizon, A. O., **Some observations on the damages resulting from the Mindanao earthquake of August 17, 1976,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 382-387. (For a full bibliographic citation see Abstract No. 1.2-3.)

Some of the major damage resulting from the Mindanao earthquake of Aug. 17, 1976, in the southern Philippines are described. Engineering lessons learned from the damage are presented, and recommendations are made for seismic code revisions.

● 8.2-12 Yoshikawa, S. *et al.*, **Some discussions on the ground motions near Gomura-Fault at Kita-Tango earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 32, Nov. 1978, 249-256.

The Kita-Tango earthquake ($M = 7.5$) occurred at the northern part of the Hyogo Prefecture in southwest Japan on Mar. 7, 1927. The structural damage was concentrated within a 5-10 km zone near the fault area. Described are the relationships among the structural damage, the subsurface characteristics at the damaged sites, the distance of the sites from the fault, and the characteristics of base rock motion near the fault.

● 8.2-13 Demir, H., **Site investigation after the Lice, Turkey earthquake and its evaluation,** *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 173, Nov. 1978, 1377-1382.

An earthquake of Richter magnitude 6.8 took place in eastern Anatolia, Turkey, on Sept. 6, 1975, at 12:20 local time. Its epicentral coordinates were 38.5° N and 40.8° E. The earthquake killed 2385 people and injured 3339. A total of 8159 buildings collapsed or were damaged beyond repair. Nearly 20,000 buildings suffered some damage. This was one of the seven or eight most destructive earthquakes experienced in Turkey during the last 50 years. As is known, the most destructive earthquake, the Erzincan earthquake, occurred on Dec. 26, 1939, and caused the death of 40,000 people and the destruction of 140,000 houses. This report is based on site investigations conducted immediately after the earthquake and describes some of the damage.

● 8.2-14 Iwasaki, T. and Kawashima, K., **Ground motions and damages to civil engineering structures due to the near Izu-Ohshima earthquake of January 14, 1978** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 187, Nov. 1978, 1489-1496.

A severe earthquake (Richter magnitude 7.0) hit the eastern part of the Izu Peninsula, Shizuoka Prefecture, on Jan. 14, 1978. The epicenter was located at N34°46′ and E139°14′, shortly west of Izu-Ohshima Island, with a very shallow hypocentral depth. Seismic intensities on the JMA scale and the locations of the foreshocks, mainshock, and aftershocks are shown. Traces of seismic faults that ruptured on National Highway Route 135 at Inatori, with a right lateral dislocation of about 18 cm, are indicated. Maximum accelerations measured by SMAC-type strong-motion accelerographs are plotted. These values are peak accelerations either on ground surfaces or at first floors or basements of low-story buildings. A relationship between epicentral distances and peak accelerations is observed. The locations of 168 cemeteries where tombstones overturned are indicated. Also shown are the ratios of the number of tombstones overturned to those tombstones examined, and peak accelerations are estimated in view of those ratios. The severity of mainshock and aftershock ground motions is compared. Figures indicate the locations of damaged highways, typical landslides which caused severe damage to the highways, a highway bank which settled, and a failed masonry retaining wall along a highway near Inatori. Figures also indicate an undamaged concrete frame retaining wall on a high bank and a damaged tunnel and damaged bridges and tailings dams.

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The characteristics of ground motions and the damage to civil engineering structures can be summarized as follows. (1) Surface dislocations caused by seismic faults were observed in the Inatori area. Landslides, slope failures, and rockfalls were extensive inside the area of aftershocks. (2) Damage to cutting slopes reinforced by surface works were minor. Damage to cutting slopes that were well designed and well maintained was less. (3) Although a number of settlements, cracks, and failures of earth banks and retaining walls were observed, there were few severe failures of this type. High earth fills enforced by frameworks did not sustain structural damage. (4) Although a few tunnels were damaged severely either because of the effects of active faults or the effects of landslides, most tunnels withstood the earthquake. (5) Most highway bridges and pedestrian bridges did not sustain damage.

● **8.2-15** Heimgartner, E. and Glauser, E. C., **Behaviour of damaged buildings during renewed earthquakes,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* Vol. III, 629–641. (For a full bibliographic citation, see Abstract No. 1.2–7.)

Between May 6 and Sept. 15, 1976, Friuli was hit by 18 earthquakes with a magnitude of $M \geq 3.8$. The increase in structural damage caused by the September shocks was investigated in buildings which had been closely examined by the authors during an earlier stay in the earthquake area. Additional building damage depended to a large extent on behavior during the first earthquake as well as on the kinds of repairs carried out in the meantime.

● **8.2-16** Gulkan, P. *et al.*, **Engineering report on the Muradiye-Caldiran, Turkey, earthquake of 24 November 1976,** Committee on Natural Disasters, National Research Council, U.S. National Academy of Sciences, Washington, D.C., 1978, 59.

This report contains brief descriptions of the geology and physiography of the region affected by the Nov. 24, 1976, earthquake in Turkey, as well as the preliminary studies and observations on the earthquake made by the members of several inspection teams. One team from the Mining Research and Exploration Inst. of Turkey concentrated its observations on the geological and tectonic features of the event. A second team from the Earthquake Research Inst. of the Ministry of Reconstruction and Resettlement collected the bulk of the data on the extent of damage and supplied complementary information on the geological aspects of the earthquake. The impressions of a group from the Middle East Technical Univ. concerning the structural damage constitute the corresponding section of this report.

There were no strong-motion instruments in the epicentral region. Two instruments, one of which was located in Van and the other in Agri, about 80 km northwest of Caldiran, received shocks large enough to be triggered, and one seismoscope located on rock in Van yielded a recording. Various estimates of the intensity of the epicentral motion are derived from these recordings.

From the viewpoint of structural engineering, the damage resulting from this earthquake is not of major interest because of the scarcity of engineered structures in the area. The seismic response of indigenous housing is, however, a problem of worldwide interest and the implications of the newly formed, and previously unmarked, fault along which most of the damage was concentrated are enough to warrant a detailed description. The studies given in this report are only preliminary evaluations and are intended to relate the first-hand impressions of a significant, magnitude 7.3 earthquake.

● **8.2-17** **The San Juan earthquake of November 23, 1977** (El terremoto de San Juan del 23 de Noviembre de 1977, in Spanish), Inst. Nacional de Prevencion Sismica, San Juan, Argentina, Dec. 1977, 103.

● **8.2-18** Psycharis, I., **The Salonica (Thessaloniki) earthquake of June 20, 1978,** *EERL 78-03,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Oct. 1978, 28.

The 6.5 magnitude Salonica earthquake of June 20, 1978, is an earthquake of major interest from the engineering point of view, because it occurred near a city of 700,000 inhabitants. In general, the damage was not extensive and modern buildings performed quite well during the earthquake, while some old ones suffered severe damage. The author was in Athens at the time of the earthquake and visited Salonica on June 23. Since the intention of this visit was to make a general survey of the affected area, detailed descriptions of the engineering features of the earthquake and building damage are not included in this report.

● **8.2-19** Buck, R. A. and Baird, B. P., **Staff report to the Seismic Safety Commission on the Santa Barbara earthquake, August 13, 1978,** California Seismic Safety Commission, Sacramento, Sept. 1978, 29.

The earthquake occurred at 3:54 p.m., Aug. 13, 1978, off the California coast near Santa Barbara (between Santa Barbara and Santa Cruz Island). Magnitude as measured by the California Inst. of Technology was 5.1 M_L (Richter scale), and by Univ. of California, Berkeley, 5.7 M_L. Depth of focus was 7 km. The California Dept. of Mines and Geology placed the highest intensity as VII on the Modified Mercalli Scale, in the vicinity of the Univ. of California in Goleta. A U.S. Geological Survey investigator assigned a

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modified Mercalli intensity of VIII to Isla Vista near the university, and VII to downtown Santa Barbara.

Seismic Safety Commission staff arrived in the Santa Barbara area on Tuesday, Aug. 15. This report is compiled from observations in the field, interviews conducted from Aug. 15 to Aug. 18 in the field, subsequent telephone conversations to verify information, and reports of state and federal agencies which conducted their own field investigations. Attachment 1 is a partial list of people interviewed by the SSC staff.

● 8.2-20 Miller, R. K. and Felszeghy, S. F., **Engineering features of the Santa Barbara earthquake of August 13, 1978,** *UCSB-ME-78-2,* Dept. of Mechanical and Environmental Engineering, Univ. of California, Santa Barbara, Dec. 1978, 135.

Although the Santa Barbara earthquake was only a moderate seismic event, several of its features were unusual and interesting from an engineering point of view. Included among these features are the geographical asymmetry of strong ground shaking, the large peak accelerations recorded by strong-motion instruments, and the differences in reported magnitudes for the event. This earthquake also provided a picture of the performance of modern California buildings in a moderate earthquake. The contents of the report follow: general features and summary; geological features; strong motion records; earthquake effects on hospitals, schools, fire and police stations; earthquake effects on transportation facilities; earthquake effects on utilities; earthquake effects on buildings; architectural, mechanical and property damage; earthquake effects on soils and dams; earthquake effects on coastal facilities and offshore platforms; and evidence of locally nonlinear behavior of structures.

● 8.2-21 Berberian, M., **Tabas-e-Golshan (Iran) catastrophic earthquake of 16 September 1978; a preliminary field report,** *Disasters,* **2,** *4,* 1978, 207-219.

● 8.2-22 Yanev, P. I., ed., **Miyagi-Ken-oki, Japan earthquake, June 12, 1978, reconnaissance report,** Earthquake Engineering Research Inst., Berkeley, California, Dec. 1978, 165.

The report consists of the following papers: *Introduction,* Blume, J. A.—*Seismicity and geologic setting,* Wentworth, C. M.—*Strong-motion earthquake recordings,* Brady, A. G.—*Liquefaction and damage to dikes,* Keefer, D. K.—*Landslides resulting from the earthquake,* Harp, E. L.—*Engineering aspects,* Cooper, J. D., Ellingwood, B. R. and Yanev, P. I.—*Architectural aspects,* Arnold, C.—*Social effects and government response,* Fowler, H. H.

● 8.2-23 Cismigiu, A., **After the Moldavian earthquake of 4th March 1977: towards new types of structures** (Dupa cutremurul Moldavic din 4 martie 1977, in Romanian), *Arhitectura,* **25,** *4,* 1977, 23. (Also available in an English version, trs. by M. Iacob, 46 pp.)

● 8.2-24 **Socialist Republic of Romania: the earthquake of March 4, 1977** (Republique Socialiste de Roumanie: le tremblement de terre du 4 mars 1977, in English or French), *Serie FMR/SC/GEO/78/102, Rapport Techinque PP/1977-78/2.161.4,* Earthquake Reconnaissance Mission, United Nations Educational, Scientific, and Cultural Organization (UNESCO), Paris, 1978, 47.

8.3 Effects on Buildings

● 8.3-1 Fintel, M., **Modern concrete structures survive Romanian earthquake,** *Civil Engineering, ASCE,* **48,** *10,* Oct. 1978, 80-81.

On Mar. 4, 1977, 35 buildings collapsed during a severe earthquake (7.2 Richter magnitude) in Bucharest, Romania. Most were older structures not designed to withstand earthquakes. Of thousands of more recent structures, built predominantly of concrete, only three failed.

● 8.3-2 Tzenov, L., Sotirov, P. and Boncheva, H., **Study of some damaged industrial buildings due to Vrancea earthquake,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-08, 1978, 59-65.

The Vrancea earthquake of Mar. 4, 1977, was felt over all Bulgaria. The buildings in the northern part of the country suffered the most serious damage. Prefabricated industrial structures withstood the earthquake very well. The earthquake intensity in some regions ranged up to intensity of VIII according to the MSK scale. An analysis of some partially damaged industrial buildings is described in this paper. The investigated structures are situated in regions where, until Mar. 4, 1977, intensities were not expected to exceed VI.

● 8.3-3 Simeonov, B., **Nonlinear seismic behaviour of Magurele building Bucharest, during the earthquake of March 4, 1977,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-48, 1978, 359-366.

During the Mar. 4, 1977, earthquake in Romania, the office building IFIN-Magurele sustained moderate damage. For the purpose of finding a means of strengthening the building, an elastic and inelastic response analysis was carried out. The analytical results show good correlation with the actual behavior of the building during the earthquake. It was determined from the analysis which elements should be strengthened and made more ductile.

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

● 8.3-4 Negoita, A. *et al.*, **Antiseismic structures with shear-walls for mass construction of tall houses,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-33, 1978, 243–250.

Primary structural damage caused by earthquakes is summarized. The behavior of embrasures and lintels is analyzed, and cracking of shear walls is discussed. Recommendations for the use of shear walls in seismic areas are given.

● 8.3-5 Stojkovic, M., **Influence of the characteristics of masonry residential buildings upon their damage caused by earthquake effect,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-03, 1978, 17–22.

In this paper the results are presented of an investigation of the damage to masonry residential buildings in Banja Luka caused by the earthquake of Oct. 27, 1969. The results are useful for reevaluating the technical codes for design of low-cost seismic-resistant masonry residential buildings.

● 8.3-6 Fajfar, P., Banovec, J. and Saje, F., **Behaviour of a prefabricated industrial building in Breginj (Yu) during the Friuli earthquake,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-66, 1978, 493–500.

In the village of Breginj, many buildings, mostly old stone masonry buildings, were heavily damaged during the 1976 Friuli earthquake. The peak acceleration of 53% g was recorded during the aftershock of Sept. 15. The elastic acceleration response spectrum for this record had a peak value of 2 g for 10% damping. However, a prefabricated reinforced concrete industrial building which was not designed to resist strong ground motion survived all shocks and was damaged only slightly. In the paper, the main characteristics of the aftershock, the static force-displacement curves, and the inelastic dynamic response of the building are shown.

● 8.3-7 Negoita, A. and Barbat, H., **The behaviour of elevated water tanks to actual earthquakes,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-63, 1978, 471–477.

The paper synthesizes important observations of the behavior of elevated water tanks during the Mar. 4, 1977, Romanian earthquake. These observations are related and compared with experimental and analytical results. Based on this comparison, suggestions are made for the seismic analysis and design of elevated concrete water tanks.

● 8.3-8 Benson & Gerdin, Inc., **Review of literature on earthquake damage to single-family masonry dwellings,** Applied Technology Council, Palo Alto, California, Apr. 29, 1977, 28.

A review and evaluation of information concerning the behavior of single-family masonry dwellings in Zone 2 earthquake areas of the United States (1973 Uniform Building Code classification) are presented. In general, reinforced masonry has sustained little or no damage in moderate earthquakes. Reported damage is often associated with poor workmanship and inspection. Unreinforced masonry (old and new) and masonry chimneys have performed poorly. Available data has been found to be limited and general.

● 8.3-9 Takiguchi, K. and Okada, K., **Damage to a five story RC hotel building due to the 1978 Izu Oshima Kinkai earthquake** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 188, Nov. 1978, 1497–1504.

On Jan. 14, 1978, the east part of the Izu Peninsula and Oshima Island were shaken strongly by an earthquake of magnitude 7.0, named the 1978 Izu Oshima Kinkai earthquake. Many buildings and houses were damaged. This paper deals with the damage to one hotel building at Inatori, which is about 20 km from the epicenter, and with the method for repairing the building. The hotel building is a five-story reinforced concrete structure built in 1967 (except for a part of the highest story which was built in 1973 and is made of steel). The plan of the building has seven column lines at 4.3 m intervals in one direction and three column lines at 10.8 m and 8.0 m intervals in the other direction. The hotel was built on a steep incline; therefore, the footings of the structure are not on identical levels. Diagonal cracks occurred in the tie beams of the lowest story, and in the short beams between the columns and walls the main damage occurred. The damage can be considered to be primarily the result of unequal settling of the ground and stress concentration. One proposal for repairing the building is as follows. First, to improve the ground under the footings, cement would be injected into the ground. The lower part of the building would be strengthened by newly constructed walls. Short beams between the columns and walls would be reinforced with newly arranged hoops.

● 8.3-10 Scelfo, A., Pino, G. and Schembri, B., **Earthquake response analysis of the new civil hospital in Tolmezzo, Friuli,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations,* **Vol. III,** 642–685. (For a full bibliographic citation, see Abstract No. 1.2-7.)

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A new hospital building in Tolmezzo, Italy, was only slightly damaged by the Friuli earthquake, in spite of its proximity to the location of a strong registration (about 363 gal) of the horizontal components of the earthquake. This paper studies the response of the entire structure which was designed for the 2nd seismic category (about 70 gal maximum ground acceleration). Because of the complexity of the structure, the analysis is carried out with a standard program for the dynamic analysis of framed structures.

● 8.3-11 Mochizuki, T., Miyano, M. and Matsuda, I., **Study on damage of wooden houses due to the great Kanto earthquake, 1923–on the relations between distance from the epicenter, landform and the ratios of totally destroyed houses** (in Japanese), *Transactions of the Architectural Institute of Japan, 270,* Aug. 1978, 81-90.

This paper investigates damage to wooden houses during the great Kanto earthquake of 1923. The relations among the epicentral distance, the landform (geology), and damage to wooden houses are shown quantitatively. The differences between damages at the upthrown block and the downthrown block of the fault are investigated. The epicenter is assumed to be a line 85 km long along the Sagami trough as a result of recent geodesic research.

● 8.3-12 **A report on damage to reinforced concrete buildings during the Oita earthquake of April 21, 1975,** Architectural Inst. of Japan, Tokyo, June 1976, 342.

The magnitude 6.4, Apr. 21, 1975, Oita earthquake is examined. The epicenter was located in a national park which minimized the amount of damage, but, because it was a shallow earthquake with a focus of 9.3 km, there was violent vertical and lateral shaking. A modern four-story concrete hotel building located 2 km from the epicenter collapsed. Damage to this and other structures is discussed.

8.4 Effects on Miscellaneous Structures and Systems

● 8.4-1 Dowding, C. H. and Rozen, A., **Damage to rock tunnels from earthquake shaking,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT2*, Proc. Paper 13533, Feb. 1978, 175-191.

Observation of rock-tunnel response to earthquake motions is compared with calculated peak surface motions for 71 cases to determine damage modes and indices. Damage ranging from cracking to closure occurred in 41 of the observations. Peak surface motions serve as the principal variables in the study since shaking affects the greatest tunnel mileage, is non-site-specific, and has the greatest likelihood of multiple occurrence. The peak motions, calculated from the Richter magnitude and distance from tunnel to causative fault, and associated damage are compared internally and externally. The internal comparison of earthquake observations yields threshold values of peak motions associated with specific modes of tunnel damage. These thresholds are then externally compared with damaging motions from explosion-test studies to determine the relative conservatism of the threshold values. The results of the comparisons indicate that the damage thresholds are conservative and that tunnels are safer than above-ground structures for a given intensity of shaking.

● 8.4-2 Youd, T. L. and Hoose, S. N., **Historic ground failures in northern California triggered by earthquakes,** *Professional Paper 993,* U.S. Geological Survey, Washington, D.C., 1978, 177.

A major source of earthquake-related damage and casualties in northern California has been ground failure generated by seismic shaking, including landslides, lateral spreads, ground settlement, and surface cracks. The historical record shows that, except for offshore shocks, the geographic area affected and the quantity and general severity of ground failures increase markedly with Richter magnitude. Hence, the largest historical event, the 1906 San Francisco earthquake, was the most important generator of ground failures. Because of recent population growth and land development in northern California, the potential for damage in future events is enormous compared with that existing in 1906.

Descriptions of ground failures resulting from the 1906 San Francisco earthquake and other northern California earthquakes are used in this report to (1) identify and clarify the types of ground failures associated with earthquakes, (2) provide a guide for engineers, planners, and others responsible for minimizing seismic hazards, and (3) form a data base for other geotechnical studies of earthquake-triggered ground failures.

Geologic, hydrologic, and topographic settings have an important influence on ground failure development as does distance from the causative fault. Areas especially vulnerable to ground failure in northern California have been oversteepened slopes, such as mountain cliffs, stream banks, and coastal bluffs, and lowland deposits, principally Holocene fluvial deposits, deltaic deposits, and poorly compacted fills. Liquefaction has been the direct cause of most lowland failures. The historical record suggests that ground failures during future large earthquakes are most likely to occur at the same or geologically similar locations as failures during previous earthquakes.

● 8.4-3 Seed, H. B., Makdisi, F. I. and De Alba, P., **Performance of earth dams during earthquakes,** *Journal of the Geotechnical Engineering Division, ASCE,* **104**, *GT7*, Proc. Paper 13870, July 1978, 967-994.

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Emphasis is given to dam performance in six major earthquakes: San Francisco (1906); Ojika, Japan (1939); Fallon, Nevada (1954); Kern County, California (1952); Tokachi-oki, Japan (1967); and San Fernando, California (1971). An attempt is made to determine relationships between embankment characteristics and observed performance. It is concluded that (1) hydraulic fill dams on stable foundations can safely withstand accelerations up to about 0.2 g from magnitude 6.5 earthquakes; (2) virtually any well built dam can withstand moderately strong shaking up to 0.2 g or more with no detrimental effects; (3) dams built of clay soils seem to be able to withstand extremely strong shaking from large magnitude earthquakes without significant damage; (4) dams may fail up to 24 hrs after being shaken by an earthquake, probably because of cracking leading to piping and erosion; and (5) primary concern should be given to dams constructed of saturated sandy soils or built on sand foundation materials. Prototype performance is cited as a basis for these conclusions.

● 8.4-4 Papastamatiou, D., **The 1601 Unterwalden earthquake, Switzerland; a contemporary account,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 5/6, Paper 6-01, 1978, 1-16.

The earthquake occurred on the night of Sept. 18, 1601, 10 to 20 km south of Luzern. The epicentral area was not extended. The ground motion interacted with the topography of the region and triggered numerous landslides and rockfalls. A major landslide into the lake of Luzern generated a wave that inflicted damage and casualties all around the shore. It is possible that the landslide was triggered by a seiche due to resonance of the lake cross section with the seismic solid waves.

The earthquake is representative of large rare events in Switzerland and, as such, is of engineering importance.

● 8.4-5 Isenberg, J., **The role of corrosion in the seismic performance of buried steel pipelines in three United States earthquakes,** *Grant Report No. 6,* Weidlinger Assoc., New York, June 1978, 80.

The role of corrosion in the seismic performance of water pipelines has been investigated in the 1965 Puget Sound, Washington; 1969 Santa Rosa, California; and in the 1971 San Fernando, California, earthquakes. The study concentrates on regions where the maximum ground displacement is thought to be of the order of 10 cm or less, and excludes regions, especially in San Fernando, where surface faulting was reported.

The present study confirms the findings of post-earthquake damage inspections which indicate that corroded pipes and service laterals comprise a significant percentage of earthquake-induced leaks. However, predictions of earthquake damage cannot be made unless the locations of corroded pipes and the extent of the corrosion are known. The finding of this study is that the pipe leak rate under normal conditions may provide a clue to its seismic performance. Once enough data have been gathered for a specific system, it may become possible to identify seismically vulnerable reaches of pipe as ones with leak rates that exceed those of other pipes or of the system as a whole. Other factors such as local geology and backfill may also play a role.

● 8.4-6 Harp, E. L. *et al.*, **Landslides from the February 4, 1976 Guatemala earthquake: implications for seismic hazard reduction in the Guatemala City area,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 353-366.

The Feb. 4, 1976, earthquake (M = 7.5) in Guatemala generated more than 10,000 landslides which were predominantly rockfalls and shallow debris slides of less than 15,000 m^3 in volume. The landslides were particularly destructive in the Guatemala City area. Guatemala City occupies a relatively flat-lying intermontane plateau of Pleistocene pumice. The plateau is deeply incised by streams that have cut steep-walled canyons, and development throughout most of the city has extended to within a few meters of these canyon margins. Without exception, rockfalls and debris slides from the earthquake were located along the canyon slopes. Rockfalls occurred as spalling failures on canyon slopes generally steeper than 50°; most of these failures were near vertical slices of rock less than 6 m thick. Debris slides occurred on slopes of between 30° and 50°, mainly in sandy soils developed on the pumice, and were generally less than 1 m thick. Both rockfalls and debris slides were heavily concentrated along narrow ridges and spurs, which suggests that the existing topography markedly amplified the level of seismic ground motion. From postearthquake U-2 photographs, 1:10,000-scale aerial photographs, and field investigations, individual landslides triggered during this earthquake were mapped at a scale of 1:12,500 for the Guatemala City area. The distribution of seismically induced rockfalls and debris slides suggests that slope gradient, topographic form, and lithologic features were primary factors controlling the occurrence of these failures. Utilizing these data, a map of the earthquake-induced landslide concentration for the Guatemala City area has been prepared showing areas of high landslide concentrations in which there is a high probability of landslide occurrence during future earthquakes.

● 8.4-7 Isenberg, J., **Seismic performance of underground water pipelines in the southeast San Fernando Valley in the 1971 San Fernando earthquake,** *Grant Report No. 8,* Weidlinger Assoc., New York, Sept. 1978, 29.

This study demonstrates that corrosion is a major factor in determining where pipeline leaks occur in areas subject to ground shaking and in seismically inactive areas as well. No methods of locating weak underground pipes are now readily available; it appears impractical to try to identify specific weak points in a complex system such as the one operated by the Los Angeles Dept. of Water and Power. A more manageable approach would be to subdivide a pipe network into regions of 1/4 km or 1/2 km on a side, and to characterize the zone by the types and sizes of pipe within the zone and the type of corrosion which characterizes that zone. No procedure for estimating the stage of corrosion and the rate of its progress presently exists. Although the data are not conclusive, they do indicate that the effects of ground shaking on pipelines continued in the San Fernando Valley for several years after the 1971 earthquake.

● 8.4-8 Yen, B. C. and Trotter, J. R., **Shallow slides due to 1971 San Fernando earthquake,** *Earthquake Engineering and Soil Dynamics,* Vol. II, 1076-1096. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The San Fernando earthquake of 1971 resulted in over 1,000 identified hillside slope failures. Of the several modes of slope failure which have been observed in San Fernando and in other seismically active areas of the world, shallow slides are by far the most common. This paper deals exclusively with shallow slope failure. Twenty-one slides were mapped in the general vicinity of Lopez Canyon. Soil samples were tested and analyzed. The slides were chosen in the San Fernando region in an attempt to define common characteristics and mechanisms attributed to this type of failure.

Field evidence indicates that many of the slides occur within the residual soil mantle overlying parent rocks or older colluvial slopes. Laboratory study suggests that the soils are predominately silty sands or clayey sands, regardless of the lithologic associations of the slides. Considering the shallow depth of the slides, the shear stress-strain relationships under low normal load appear to be significant in choosing strength parameters for analyzing slope stability. Because of the low ratio of depth to length of the slides and their planar mode of failure, a one-dimensional mathematical model with an equivalent inertia term is used to account for the accumulative shaking effect causing failure. The model assumes an elastic soil layer bonded to a rigid plastic base. As all the cases studied failed during the 1971 earthquake, back calculations from surveyed and tested conditions are used to check the validity and applicability of the theoretical model for evaluating seismically induced shallow slope failures.

Although more research is needed to further understand the frequently occurring but largely neglected problem of seismically induced shallow hillside failures, the paper concludes that the simple one-dimensional approach shows promise for estimating slide stability. The method of analysis and field data discussed in the paper could serve as rational guides for planning structure setback or transportation and utility corridors in seismically active foothill regions.

8.5 Effects and Near Surface Geology

8.5-1 Bower, D. R. and Heaton, K. C., **Response of an aquifer near Ottawa to tidal forcing and the Alaskan earthquake of 1964,** *Canadian Journal of Earth Sciences,* **15,** *3,* Mar. 1978, 331-340.

Coincident with the 1964 Alaskan earthquake, the water level in a deep well near Ottawa showed a small initial rise, then a fall of 28 cm, followed by a return to the original level over a period of several days. This is suggestive of a residual dilatation with subsequent fluid diffusion. It is shown that this explanation is consistent with the diffusion and elastic properties of the aquifer determined independently from a slug test and from the response to earth tides. Assuming a simple unconfined saturated porous halfspace, the results indicate that the upper 200 m (approximately) is effectively decoupled from horizontal stresses, whereas below this depth a permanent dilatation of approximately 2.9×10^{-7} occurred. This is too large and of the wrong sign to be accounted for by the residual strain field of the earthquake. As an alternative, dilatancy induced by strong local ground motion is suggested.

● 8.5-2 Youd, T. L., **Major cause of earthquake damage is ground failure,** *Civil Engineering, ASCE,* 48, *4,* Apr. 1978, 47-51.

Ground failure is one of the most destructive effects of large earthquakes and is thus a primary concern of engineers responsible for construction in seismic areas. Susceptibility to ground failure can usually be assessed on a case by case basis using geotechnical investigations and analyses. Techniques are also available for stabilizing some sites; but, for several types of failures and conditions, practical stabilizing techniques are not available. In the latter instances, limited development may be the most practical mitigating measure against earthquake damage. Assessment of the ground failure hazard and preventive or mitigating measures requires specialized geotechnical analyses and expertise.

● 8.5-3 Agnew, D. C. and Sieh, K. E., **A documentary study of the felt effects of the great California earthquake of 1857,** *Bulletin of the Seismological Society of America,* **68,** *6,* Dec. 1978, 1717-1729.

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

Over 60 hitherto unpublished accounts of the California earthquake of Jan. 9, 1857, were collected and used, together with those already known, to estimate felt intensities and to prepare an isoseismal map which roughly indicates the level of short-period ground motion experienced during this earthquake. Modified Mercalli intensities of VI to VII occurred in the modern metropolitan areas of southern California, and intensities of VI to VIII occurred in the southern San Joaquin Valley. The intensity along the San Andreas fault was IX or more. Instances of seiching, fissuring, sandblows, and hydrologic changes were reported from Sacramento to the Colorado River delta. Most reports say that shaking lasted between one and three minutes. At least two large aftershocks occurred within a week of the main event.

● 8.5-4 Gutdeutsch, R., **Macroseismic observations of the Friuli earthquake of May 6, 1976,** *Proceedings of Specialist Meeting on the 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations*, Vol. I, 135-147. (For a full bibliographic citation, see Abstract No. 1.2-7.)

Macroseismic data of the Friuli earthquake taken from regions in Austria are discussed. These data, compiled by the Zentralanstalt fur Meteorologie und Geodynamik, Vienna, have been represented as isoseismals, which show a considerable deviation from the shape of a concentric circle. These deviations permit conclusions to be drawn about the parameters of the focus and the local transmission function of seismic energy. The influence of the epicentral distance is removed from the local intensity by use of a formula. Maps of relative intensities represent the conditions of the local geological substructure and yield insights into the problems of seismic risk in the areas of concern. The areas of the Inn, Salzach, and Drau valleys have somewhat high relative intensities. This is a consequence of unconsolidated sediments of minor thicknesses. In contrast to this, the Bohemian massive area has less than normal relative intensities because of underground granite. These results agree with the results gathered from local earthquakes in Austria.

● 8.5-5 Youd, T. L., Yerkes, R. F. and Clark, M. M., **San Fernando faulting damage and its effect on land use,** *Earthquake Engineering and Soil Dynamics*, Vol. I, 1111-1125. (For a full bibliographic citation, see Abstract No. 1.2-11.)

The San Fernando, California, earthquake was the first in the United States to be associated with surface faulting in an urban area. Maximum components of displacement across the ruptured fault zone were 1.8 ft (0.5 m) horizontal shortening, 6.2 ft (1.9 m) left lateral slip, and 4.6 ft (1.4 m) vertical slip. Damage was concentrated in the zone of faulting, particularly in areas of large or concentrated fault displacement. Horizontal shortening caused buckling of foundations, floors, pavements, and pipelines. It also caused slippage between these structures and the adjacent ground, resulting in additional damage at nearby locations. Lateral slip caused shearing, stretching, and compressional damage. Vertical displacements caused tilting and fracturing of buildings, pavements, and pipelines. Field reconnaissance studies in 1977 revealed that, with the exception of the change in land use at one site from hospital to commercial-industrial, the 1971 faulting has had no apparent influence on land use in the fault zone. Buildings have been repaired, new buildings have been built, and a freeway interchange has been constructed across the trace of the 1971 fault rupture.

● 8.5-6 Flores-Berrones, R. J. and Dawson, A. W., **A liquefaction case history, Chiapas, Mexico,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings*, Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/11, 1977, 237-240.

A series of small magnitude (4.5 to 5.5 on the Richter scale), shallow-foci earthquakes struck the area near the confluence of two rivers in the state of Chiapas, Mexico, during the latter part of 1975. The earthquakes caused repeated widespread liquefaction in recent alluvial sands located adjacent to the river and within a distance of 6 km from the general epicentral area. Evidences of liquefaction consisted primarily of cracks oriented parallel to the alluvium-terrace contact from which water and liquefied sand flowed. It is believed that this type of liquefaction is typical when the topography of the recent alluvium is relatively flat and when a cohesive surface layer is present. A number of other phenomena such as bank failures are described.

● 8.5-7 Carrillo-Gil, A., **Seismic effects on the soils of Peru,** *Ninth International Conference on Soil Mechanics and Foundation Engineering, Proceedings*, Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Vol. 2, Paper 4/5, 1977, 201-202.

The effects are examined of severe earthquakes on soils in Peru. For the 1974 earthquake, correlations are established between the distribution of modified Mercalli intensities and the elastic moduli of the various types of soils in Lima and vicinity. It is concluded that intensity is greater in soils with low elastic moduli and that such soils tend to experience ground amplification effects or soil settlement, while soils with higher elastic moduli experience lower intensity and less damage.

● 8.5-8 Eiby, G. A., **The Milford Sound earthquake of 1976 May 4,** *Bulletin of the New Zealand National Society for Earthquake Engineering*, **11**, 3, Sept. 1978, 191-192.

The Milford Sound earthquake of May 4, 1976, was the largest shallow earthquake in New Zealand since the

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Inangahua earthquake of May 23, 1968. The next most recent shock of comparable size was on May 24, 1960, and was also centered in Fiordland. All three shocks were assigned a magnitude (M_L) of 7.0. Characteristics of the earthquake are described in this paper, and a map showing modified Mercalli intensities is included.

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9. Earthquakes as Natural Disasters

9.1 Disaster Preparedness and Relief

● 9.1-1 Shah, H. C., Kiremidjian, A. S. and Monzon, H., **Seismic risk analysis for lifelines—a state of the art report,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 1, Paper 1-08, 1978, 53–62.

The main aspects of the methodology for seismic risk analysis of lifelines are identified. The concepts of performance criteria and acceptable risk are discussed as they pertain to the specific problem of lifelines. The most recent contributions in the literature dealing with the questions of lifeline system identification and reliability, seismic risk modeling for lifelines, and performance criteria are reviewed.

● 9.1-2 Mitchell, W. A., Wolniewicz, R. and Kolars, J. F., **Predicting casualties and damages caused by earthquakes in Turkey: a preliminary report,** *USAFA-TN-78-2,* Dept. of Economics, Geography and Management, U.S. Air Force Academy, Colorado, Mar. 1978, 30.

This study provides a model for use by Turkish and American authorities in responding to earthquake disasters in Turkey. Specifically, the objective was to construct a model which would estimate casualties and damages within minutes after an earthquake occurs in order to determine the need for international and U.S. government relief assistance. It was found that western Turkey has experienced proportionately fewer casualties and damages than eastern Turkey, and that the amount of energy released by the earthquake, the geologic foundation, and the quality of building construction are critical in predicting deaths and damages.

● 9.1-3 Munroe, T. and Lawson, L., **Benefit-cost analysis of earthquake warning systems,** *Sixth European Conference on Earthquake Engineering,* Yugoslav Assn. for Earthquake Engineering, Ljubljana, Vol. 2, Paper 2-74, 1978, 553–560.

In recent years a significant effort has been directed toward the development of earthquake prediction systems, resulting in many controversies over the politics, economics, and engineering of warning systems. This paper utilizes an ordinal ranking scheme to develop guidelines for conducting benefit-cost analysis of such warnings. The rankings are then applied to several types of warnings with some speculation about the actual magnitude of the benefit-cost ratios involved. This study indicates that warnings of a few weeks lead time may be less efficient than warnings of either shorter or longer lead time.

● 9.1-4 Rikitake, T., **Classification of earthquake prediction information for practical use,** *Tectonophysics,* **46,** *1/2,* Apr. 4, 1978, 175–185.

By analyzing precursory times of existing earthquake-precursory data, "time windows" for periods during which an earthquake of magnitude 6 or greater is likely to occur are established. A time window is defined as a time range during which the cumulative probability of an earthquake occurrence increases from 30% to 80%. The paper classifies time windows into three groups, with earthquakes predicted: (1) within several hours; (2) within a few days; and (3) within an unknown but short period of time. The classification depends upon whether the precursors have extremely short or moderately short precursor times.

Reliability of the time-window classification data is given one of three ratings: X-highly reliable; Y-slightly less reliable; and Z-possible. It is hoped that by combining time window and reliability classifications some criteria

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will exist for emergency control of the public if a damaging earthquake is believed to be impending.

● 9.1-5 Nichols, D. R. and Matthews, R. A., **The U.S. Geological Survey's role in geologic-related hazards warning,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1531-1537.

In response to the Disaster Relief Act of 1974 and subsequent delegations of authority, the U.S. Geological Survey published in the *Federal Register* a description of its capabilities for predicting geologic-related hazardous events, and proposed procedures for providing such information to government officials and the general public. Three levels of geologic-related hazard information were defined: notice of potential hazards, hazard watch, and hazard warning. Although the procedures have not been adopted formally, examples of four potential hazards have been brought to the attention of public officials during the past 18 months: (1) a rockfall in Billings, Montana; (2) an active fault in Ventura, California; (3) potential hazards from ground fissuring and faulting in Las Vegas Valley, Nevada; and (4) a landslide near Kodiak, Alaska. In these cases, the role of the Geological Survey was to identify and document a hazard and to communicate technical information. Recommendations or orders for defensive action are issued by officials of state and local government, because the police and the public safety authority rests in our governmental system.

● 9.1-6 **Disaster relief—case report Turkey-earthquake September 6, 1975,** Office of Foreign Disaster Assistance, Agency for Intl. Development, Washington, D.C. [1977], 4.

A magnitude 6.7 earthquake occurred in eastern Turkey on Sept. 6, 1975. The earthquake affected mainly the provinces of Diyarbakir, Bingol, and Mardin. The epicenter was at the town of Lice, which was totally destroyed. Several thousand people were killed or injured, and more than 7,000 homes were destroyed.

● 9.1-7 von Einsiedel, N., **Vulnerability analysis of natural disaster risks for the Metro Manila area,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 86-98. (For a full bibliographic citation see Abstract No. 1.2-3.)

Limited attention has been given in the past to the risk of natural disasters in the planning process for most developing countries. To overcome a major part of this problem, the United Nations Disaster Relief Organization (UNDRO) has advocated the formulation and application of a general methodology for analyzing disaster vulnerability in the urban planning process. The Philippine government through the Human Settlements Commission requested the assistance of the UNDRO in undertaking a systematic vulnerability analysis of the metropolitan Manila area. The results will be used to develop a composite risk map for the comprehensive plan for Manila. This paper deals with the methodologies and factors connected with the analysis of Manila which is a fairly flat area, with little differences in typhoon risk from one zone to another, and with no major risk of landslides. Earthquakes and floods are two major causes of disasters. The applicability of this technology to land use planning in the area is briefly discussed.

● 9.1-8 **Earthquake response plan,** California Office of Emergency Services, Sacramento, Nov. 1977, 70.

This plan was prepared in compliance with the California Emergency Plan, which identifies an earthquake as one of the peacetime emergencies for which contingency plans are required. The plan provides public officials with the degree and nature of the potential problems that might confront them and the type of response that would be needed following a major earthquake. It contains specialized operational concepts and emergency actions, with specific application to the unique aspects of a large and devastating earthquake. Special consideration was given to use of the organizational and operational concepts outlined in the widely accepted and utilized California Fire and Rescue Emergency Plan and the California Law Enforcement Mutual Aid Plan. These concepts require the designation of coordinators for various functions such as disaster medical care, fire and rescue, transportation, engineering, law enforcement, and housing at each level of the emergency organization: local city, county or operational area, mutual aid region, and state. This approach requires jurisdictional or service plans whereby individuals are charged specifically with the responsibility for directing or managing response efforts or resources. General titles are used in reference to Federal preparedness and relief programs. Specific disaster relief laws, rules and regulations are provided in part two of the plan. Listings of key personnel, resources, and predesignated facilities needed for implementation of this plan are to be provided and maintained by concerned state and local governmental agencies.

● 9.1-9 Shinozuka, M., Takada, S. and Kawakami, H., **Risk analysis of underground lifeline network systems,** *Proceedings of the U.S.-Southeast Asia Symposium on Engineering for Natural Hazards Protection,* 44-58. (For a full bibliographic citation see Abstract No. 1.2-3.)

A methodology of risk analysis for underground lifeline systems is developed and applied to the water transmission system in Tokyo. The topological or the network characteristics of the system are analyzed for the evaluation of its possible unserviceability. The unserviceability basically results from failures of the water pipelines under earthquake acceleration and depends on the local ground conditions, the intensity of the earthquake and the resisting

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capacity of the pipe structure. The local ground conditions, and the intensity and the occurrence of earthquakes are treated as random quantities with characteristics unique to the Tokyo area. The probability of unserviceability of the system subjected to an earthquake of a specific intensity is evaluated for the system.

● 9.1-10 Fujiwara, T., **Automatic train stopping system during earthquake (first report)** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978*, Architectural Inst. of Japan *et al.*, Tokyo, Paper No. 44, Nov. 1978, 345-352.

The fundamental model of a new automatic system for stopping trains during an earthquake was presented at the 6th World Conference on Earthquake Engineering in 1977. The subsequent results of the research are described in this paper. The purpose of the system is to stop trains just after the first tremor. The system is based on the following two ideas. One is the setting of seismic detection points away from a railway line toward the expected foci as well as along the line. The other is the prediction of the amplitude of subsequent maximum motion from the waveform of the initial motion of P-waves. The high-speed railway line, the Tohoku Shinkansen, is now under construction in the northeastern region of Japan.

● 9.1-11 Anton, W. F., **A utility's preparation for a major earthquake**, *Journal of the American Water Works Association*, June 1978, 311-314.

The East Bay Municipal Utility District is located on the east side of San Francisco Bay where two major active faults cross its service area, two active faults cross its supply aqueducts, and its service area is subject to major ground shaking from the San Andreas fault on the west side of San Francisco. The district must be particularly concerned with preparing for and rapidly recovering from a major earthquake. The district's actions to minimize seismic damage are outlined.

● 9.1-12 Harigaya, T. and Endo, H., **Redevelopment of Shirahige Higashi area in Tokyo**, *Civil Engineering in Japan*, **17**, 1978, 120-133.

This paper describes major earthquakes which have occurred in the Tokyo area and the effects these earthquakes have had on structures and the population. In light of these earthquakes and the strong potential for future large earthquakes, the Tokyo Metropolitan Government has developed a plan for the redevelopment of the Koto area, which includes the Shirahige-Higashi district. This plan includes the acquisition of vacant factories for use as shelters in case of a destructive earthquake and the construction of highrise apartment buildings to serve as fire barriers to the shelter areas. This plan is described and maps of the area are given.

● 9.1-13 Rogers, D. L., **Issues faced in programming *Guatemala disaster rehabilitation* assistance: views and impressions of an agency programmer**, *Mass Emergencies*, 3, 4, Dec. 1978, 229-237.

● 9.1-14 Mitchell, W. A. and Miner, T. H., **Environment, disaster, and recovery: a longitudinal study of the 1970 Gediz earthquake in western Turkey**, *USAFA-TR-78-11*, Dept. of Economics, Geography and Management, U.S. Air Force Academy, Colorado, Nov. 1978, 139.

On Mar. 28, 1970, an earthquake of Richter magnitude 7.1 occurred near the town of Gediz in western Turkey. The death toll was 1086 people; 1265 were injured in the disaster. The earthquake had a disastrous effect in 313 villages and towns, demolishing 14,852 homes and damaging 5105 others. Soon after the emergency, the Turkish government implemented a vast relief, recovery, and reconstruction program which included rebuilding the town of Gediz and building 9099 houses throughout the damaged area. This report is a comprehensive analysis of the disaster from its beginning through the summer of 1978.

9.2 Legal and Governmental Aspects

● 9.2-1 Perkins, J. B., **The use of earthquake and related information in regional planning—what we've done and where we're going**, *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application*, National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 315-321.

ABAG (Association of Bay Area Governments) is a regional comprehensive planning agency that is owned and operated by the local governments of the San Francisco Bay area. It was established in 1961 to meet regional problems through the cooperative action of its member cities and counties. ABAG has used several techniques for combining earth science maps. These techniques include land capability analysis and various methods of calculating maximum earthquake intensity and cumulative economic risk resulting from earthquake damage. The resulting maps and data are more easily used in ABAG's planning programs, including: (1) providing data on characteristics of large vacant industrial sites and potential seaports, (2) locating areas deserving further study for use as potential disposal sites for hazardous wastes, (3) assessing the impacts of alternative future land use alternatives, (4) reviewing regionally significant development proposals on a continuing basis, and (5) providing information to city and county staff. ABAG's earthquake program plans to refine existing earthquake maps by experimenting with the ways in which other relationships among geology, faults, topography, earthquake recurrence intervals, and damage affect these maps. ABAG also expects to relate these maps more systematically to various land development patterns.

● 9.2-2 Remmer, N. S., **Government responsibility in microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 215-225.

On June 22, 1978, the President of the United States presented to the Congress a report entitled "A National Earthquake Hazards Reduction Program." The program identifies priorities and responsibilities of federal, state and local governments, and outlines private responsibilities. It also reviews current and projects future technical capabilities. The importance of regional, local, and specific site seismic hazard characteristics is emphasized in relation to government land-use control programs and specific site evaluation responsibilities. California and Massachusetts programs for earthquake hazard reduction provide interesting examples of the present status of state and local governments at opposite ends of the earthquake-hazard spectrum and their relationship to the federal program. Finally, the potential of linking land-use control and prediction capability for existing buildings presents the possibility for state and local governments to fulfill their responsibility in a realistic way.

● 9.2-3 Lagorio, H. J. and Botsai, E., **Urban design and earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 193-202.

Despite many technological advances in earthquake engineering and prediction, major U.S. cities remain vulnerable to major seismic events. It is fortunate that, since the 1906 San Francisco earthquake, a major U.S. metropolitan center has not been hit directly by a severe or even a moderate earthquake. Risk to populations exposed to earthquakes is most critical for those living in highly congested urban centers. Because of rapidly increasing populations and building construction in well established urban areas, recurrence of a major earthquake would result in much greater damage and life loss than ever before. Urban design as an emerging branch of architecture is identified with the rapid urbanization of the last three decades. Assessment of the physical growth of cities indicates that potential urban design principles involving hazards mitigation are overlooked or that some consequences of urban design decisions are not foreseen because of the complexity of required interdependent activities, services, and functions.

● 9.2-4 Hart, E. W., **Zoning for the hazard of surface fault rupture in California,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. II, 1978, 635-646.

Under provisions of the Alquist-Priolo Special Studies Zones Act of 1972, the State of California establishes regulatory zones to mitigate the hazard of surface fault rupture. The regulatory zones are delineated to encompass traces of the San Andreas and other hazardous faults. Regulation of most proposed development projects within the zones is carried out by affected cities and counties. In most cases, geologic site investigations are required prior to development and structures for human occupancy cannot be sited astride active, identified faults. The investigative reports are reviewed by local governments for adequacy and subsequently filed with the State Geologist. Although the fault-rupture hazard is generally considered to be the most readily mitigated geologic hazard, accurate location and evaluation of faults appear to be more difficult than initially anticipated.

● 9.2-5 Olson, R. A., **The policy and administrative implications of seismic microzonation: toward logic or confusion?,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. III, 1978, 1475-1487.

The application of microzonation in earthquake hazard reduction programs is examined. A review of two actual earthquakes and one simulated earthquake illustrates the issues.

● 9.2-6 **Seismic safety plan: an element of the general plan, Santa Clara County,** Santa Clara County, California, Planning Dept., San Jose, 1976, 119.

This paper presents information on existing land use in Santa Clara County, California, and gives a comprehensive account of the county's geologic conditions. Soil instability, either with or without seismic upheaval, and its effect on buildings are analyzed. Structural designs that best withstand seismic shock are reviewed. Recommendations are made for minimizing the risks of earthquake damage in the context of present economic and social conditions.

● 9.2-7 **State Mining and Geology Board's Annual Report to the Governor and Legislature, 1977,** *California Geology,* 31, *5,* May 1978, 117-120.

● 9.2-8 Kreimer, A., **Post-disaster reconstruction planning: the cases of Nicaragua and Guatemala,** *Mass Emergencies,* 3, *1,* Mar. 1978, 23-40.

This study discusses the 1972 Nicaragua earthquake and the 1976 Guatemala earthquake. In both cases, the disastrous effects of the earthquake compounded already

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substandard conditions and exposed these poor conditions to public attention. The different strategies adopted for relief and reconstruction in the two countries are examined.

● 9.2-9 Margerum, T., **Will local government be liable for earthquake losses? What cities and countries should know about earthquake hazards and local government liability,** Assn. of Bay Area Governments, Berkeley, California, Jan. 1979, 32.

This report examines the potential liability of a local government with regard to seismic hazards. The nature and extent of the liability are clarified.

● 9.2-10 **Environmental hazards element: comprising the Marin County seismic safety and safety elements and environmental impact reports,** rev. ed., Marin County Comprehensive Planning Dept. [San Rafael, California], 1977, 108.

● 9.2-11 **The National Earthquake Hazards Reduction Program,** U.S. Executive Office of the President, Washington, D.C., June 22, 1978, 30.

This report describes the National Earthquake Hazards Reduction Program. In accordance with the Earthquake Hazards Reduction Act of 1977, the purpose of the program is to reduce the risks to life and property from earthquakes in the United States. The Act (Public Law 95-124) directs the President "to establish and maintain an effective earthquake hazards reduction program." To implement such a program, the President is to develop a plan, which shall "set year-by-year targets through at least 1980, and shall specify the roles for Federal agencies and recommend appropriate roles for State and local units of government, individuals, and private organizations."

● 9.2-12 Culver, C. G. *et al.*, **Plan for the assessment and implementation of seismic design provisions for buildings,** *NBSIR 78-1549*, Center for Building Technology, U.S. National Bureau of Standards, Washington, D.C., Nov. 1978, 31.

This report is a plan for the assessment and implementation of tentative seismic design provisions developed by the Applied Technology Council as part of the "Cooperative Federal Program in Building Practices for Disaster Mitigation" of the U.S. National Science Foundation and the U.S. National Bureau of Standards. The plan was prepared based on comments received from representatives of the building community. The National Bureau of Standards invited participation from a broad spectrum of interests to help develop the plan. Trade associations, industry groups, professional organizations, the model code organizations, standards organizations, and governmental agencies were included; groups with national representation rather than regional or local interest were selected. The four phases of the plan are discussed.

9.3 Socio-Economic Aspects

● 9.3-1 Hutton, J. R. and Mileti, D. S., **Social aspects of earthquakes,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 179-192.

Recent natural hazards policy studies indicate discouraging trends in U.S. earthquake losses and in the use of adjustments, such as earthquake-resistant construction, to mitigate earthquake hazards. The potential for catastrophic losses from large earthquakes is increasing. It has been found that some current adjustment practices do help reduce losses from moderate earthquakes but may ultimately increase losses from large earthquakes. Furthermore, research indicates that only a comprehensive approach—one that encourages the use of a locally appropriate mix of adjustments—can curb the increase in the potential for catastrophe from large earthquakes. Potentially, microzonation can make a substantial contribution to mitigating the effects of large earthquakes and associated hazards. Microzoning studies may also provide a stimulus to initiate comprehensive programs of earthquake hazard management. In order to provide the basis for effective hazard reduction programs, microzonation studies must be performed by experienced multidisciplinary technical teams working in direct conjunction with a variety of public and private officials.

● 9.3-2 Steinbrugge, K. V., **Earthquake insurance and microzonation,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.*, San Francisco, Vol. I, 1978, 203-213.

Microzonation applications to earthquake insurance are cost limited by the size of insurance premiums. High-value buildings with high premiums allow a detailed examination of site-specific geotechnical information. On the other end of the economic scale, low-value buildings (such as wood frame dwellings) have low premiums. It follows, then, that generalized microzonation maps are most useful for low-value buildings. Experience indicates that generalized microzonation maps are most effective if they relate soil characteristics to monetary loss patterns by class of construction material. Applying microzonation maps showing active faulting to dwellings is difficult for economic reasons while assessment of the potential for landslides is difficult technically and economically. A review of public response to earthquake insurance in geologically hazardous areas indicates that insurance penalties do not deter the house-buying or insurance-buying public.

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● 9.3-3 Abolafia, M. and Kafka, A. L., **Toward a measure of socio-seismicity,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1489-1497.

Most seismic risk maps rely on a composite of historical seismicity and tectonic principles to estimate earthquake risk. Despite the increasing sophistication of such maps, a concern with life and property requires the inclusion of social variables, such as population and structural density, in the estimation of seismic risk. It is evident that a magnitude 7.0 earthquake in a highly populated region will cause far more damage than an earthquake of the same magnitude in a sparsely populated region.

Using data from the U.S. Census of Population and Housing, this paper suggests several measures which unite social and seismic variables. Estimates of persons per square mile and the percent of single family housing structures in a region are weighed against the risk of earthquakes in a cross section of major risk regions in the United States. The variation in socio-seismicity between places with equivalent seismic risk is interpreted in terms of its relevance for policy planning. If applied to the entire United States, this new measure would extend and improve the usefulness of seismic risk maps.

● 9.3-4 Themptander, R., **Earthquake and insurance,** *Proceedings of the Second International Conference on Microzonation for Safer Construction—Research and Application,* National Science Foundation *et al.,* San Francisco, Vol. III, 1978, 1525-1530.

This paper deals with some of the problems that the insurance industry presently will encounter with earthquake insurance. Additional future problems arising from the foreseen development of earthquake prediction are mentioned, and in a few cases possible solutions are indicated.

● 9.3-5 Slovic, P. *et al.,* **Preference for insuring against probable small losses: insurance implications,** *The Journal of Risk and Insurance,* **XLIV,** *2,* June 1977, 237-257.

Laboratory studies of insurance decision-making show that people buy more insurance against events having a moderately high probability of inflicting a relatively small loss than against low-probability, high-loss events. Two explanations are discussed, both contrary to traditional utility theory. One postulates a utility function convex over losses. The second asserts that people refuse to protect themselves against losses the probabilities of which are below a certain threshold. This research provides insight into other, often puzzling facts about people's insurance behavior. Relevance for public policy is discussed.

● 9.3-6 Kuribayashi, E. and Tazaki, T., **An evaluation study on the distribution of property losses caused by earthquakes** (in Japanese), *Proceedings of the Fifth Japan Earthquake Engineering Symposium-1978,* Architectural Inst. of Japan *et al.,* Tokyo, Paper No. 177, Nov. 1978, 1407-1414.

A statistical model is employed to evaluate the monetary value of property damaged by earthquakes. The use of monetary value for evaluating seismic loss is a convenient means of comparing damage to various kinds of facilities. The property loss is calculated by multiplying the existing property in the seismic area by the loss ratio. The loss ratio is represented as a function of the magnitude of the earthquake, the epicentral distance, and the subground condition. The subground condition is divided into two simplified categories, alluvium, and diluvium and tertiary. The value of property is estimated from the National Wealth Survey of Japan. The data of eighteen earthquakes which have occurred in Japan since 1923 are used in the analysis. The following conclusions are made: (1) The property loss can be used to evaluate the scale of the earthquake disaster; (2) The property loss can be estimated by the magnitude of the earthquake, the epicentral distance, and the subground condition; and (3) Buildings and highway facilities are likely to suffer average loss. Agricultural, river, and harbor facilities are likely to suffer greater than average loss. Electrical power, telecommunications, and water supply facilities are likely to suffer less than average loss.

● 9.3-7 Omote, S., **Human behavior and psychology at the time of destructive earthquake,** *HOPE International JSME Symposium—Hazard-free Operation against Potential Emergencies,* Japan Society of Mechanical Engineers, Tokyo [1977], 7-14.

In establishing the most effective countermeasures against earthquake hazards and the most practicable relief measures to be taken at the time of a severe destructive earthquake, the problem of human behavior and psychology in the midst of violent earthquake motions has become the object of attention. In this paper, the results of two questionnaire surveys are treated. One survey was carried out in the Tokyo area with people questioned about their anticipated reactions to a possible very large earthquake. The other survey was carried out soon after an actual large destructive earthquake. The results indicate that human behavior and psychology become much more unstable in the case of an actual earthquake than an assumed earthquake.

● 9.3-8 Gurpinar, A. *et al.,* **Feasibility of mandatory earthquake insurance** (Zorunlu deprem sigortasi uygunlugu, in Turkish), 78-05, Earthquake Engineering Research Inst., Middle East Technical Univ., Ankara, 1978, 71.

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In this report, various aspects of the problems related to mandatory earthquake insurance implementation in Turkey are treated. The basic premise of the report is that the object of earthquake insurance is the improvement of construction quality in seismic regions. Problems of feasibility and applicability in achieving this goal are discussed. A methodology for the calculation of insurance premiums is developed and applied to the city of Denizli. It is concluded that mandatory insurance can improve the quality of construction if appropriate legal and institutional measures are taken. It is pointed out that an additional benefit of earthquake insurance would be the accumulation of funds for post-disaster repair and reconstruction. The report includes recommendations for preparatory research and groundwork for the legal procedure.

● 9.3-9 **Earthquake insurance issues,** Assn. of Bay Area Governments, Berkeley, California, Sept. 1977, 14.

This report examines earthquake insurance issues. It does not advocate insurance as a solution to many complex problems. An earlier ABAG booklet, *Earthquake Issues and Objectives*, provides the context in which this booklet should be viewed. This report responds to a request by local governments for more information on the implications of earthquake insurance. Although earthquake insurance is not a policy in its own right, it can help achieve several earthquake preparedness objectives. Such objectives include reducing post-earthquake economic disruption, encouraging appropriate recognition of hazardous areas in land development, decisions, and encouraging mitigation of hazardous structures or structural components.

● 9.3-10 Mitchell, W. A. and Barnes, C. T., **Change after an earthquake disaster in western Anatolia,** *USAFA-TR-78-5*, Dept. of Economics, Geography and Management, U.S. Air Force Academy, Colorado, Jan. 1978, 58.

Planned development has led to relatively rapid changes in rural Turkey. Based on field research in the country, this report examines and describes some of the changes that occurred when an unplanned disruptive natural force confronted a rural area of a developing country. Detailed relative change over a three-year period is compared for a village damaged by the 1970 Gediz earthquake and for an undamaged village in the same region. Changes are interpreted for a group of 34 seismically damaged villages and for 13 undamaged "control" villages.

● 9.3-11 Burton, I., Kates, R. W. and White, G. F., **The environment as hazard,** Oxford Univ. Press, New York, 1978, 240.

This book summarizes current knowledge about how individuals and groups respond to such natural hazards as earthquakes, floods, cyclones, and droughts. Particular attention is given to the disaster relief and planning policies of Nicaragua. A bibliography and a combined author-subject index are included.

● 9.3-12 **California earthquake zones and risk assessment,** Reinsurance Offices Assn., London, Aug. 1976, 13.

The NAIC-NCPI California Earthquake Study Technical Committee was charged with studying and developing a means for recording earthquake liability and measuring the probable maximum loss exposure of all insurance companies. The first stage of this program involves only California which is the state with the greatest earthquake recurrence interval. However, it is the intent that the developed formula be adaptable country-wide to any area with a known special earthquake hazard.

The NAIC-NCPI California Earthquake Study Subcommittee charged the Technical Committee with developing a program for determining capacity which will include habitational, commercial, industrial, and public properties. The Technical Committee has met on two occasions and, as a result of these meetings, has developed preliminary recommendations for zoning and the development of statistical data needed to determine the earthquake exposure in California.

● 9.3-13 Meltsner, A. J., **Public support for seismic safety: where is it in California?,** *Mass Emergencies*, 3, 2/3, Sept. 1978, 167-184.

● 9.3-14 Kunreuther, H. *et al.*, **Disaster insurance protection: public policy lessons,** John Wiley & Sons, New York, 1978, 400.

This study explores the decision-making processes of individuals and the institutional channels that cause us to fail to protect ourselves against disastrous, low-probability events such as earthquakes. The attitudes of individuals toward mitigation and relief policies are discussed, as well as the characteristics of hazard-prone regions and communities. Solutions are proposed for overcoming the lack of public concern about protecting ourselves against the consequences of natural hazards.

● 9.3-15 Douty, C. M., **The economics of localized disasters: the 1906 San Francisco catastrophe,** *Dissertations in American Economic History*, Arno Press, New York, 1977, 402.

Although the present study deals in considerable detail with the 1906 earthquake and fire in San Francisco, it is broader in scope than a case study. Unlike most disaster studies, it covers not only the emergency period created by the catastrophe itself, but also the period of recovery and

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

reconstruction. The point of view is primarily economic, but the contributions of other social science disciplines, notably sociology, to understanding disaster phenomena are also considered. The study examines the conditions essential for recovery from the destruction caused by natural disasters, and it has some relevance to the perplexing problems of reconstructing urban areas affected by civil disorders.

● **9.3-16** Quarantelli, E. L., ed., **Disasters: theory and research**, *Studies in International Sociology, 13,* SAGE Publications, Inc., London, 1978, 282.

This volume presents a collection of international contributions on specific areas of the current sociological research and analysis of disasters. The essays give theoretical overviews of research, summaries of work undertaken, and case studies. Of interest to those individuals concerned with seismic safety are two essays: "Levels of Trust and Reactions to Various Sources of Information in Catastrophic Situations" and "Human Behavior in the Event of Earthquakes."

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