Abstract Journal in Earthquake Engineering

Volume 5: 1975 Literature
December 1976
Earthquake Engineering Research Center
University of California, Berkeley

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NATIONAL SCIENCE FOUNDATION

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Editors: W. E. Wagy and R. C. Denton. *Editorial Assistance:* T. von Adelung, G. Fencsik, P. A. Winston, B. Bolt, Y. Mengi, R. E. Dayce and E. A. McCutcheon. *Circulation Manager:* M. Stallings.

Abstract Journal in Earthquake Engineering, Volume 5, December 1976. Published annually by the Earthquake Engineering Research Center, University of California, 47th Street and Hoffman Boulevard, Richmond, California 94804. Annual subscription price US$ 20.00. If airmail delivery is required, please add US$ 4.00 for postage. Price subject to change without further notice.

Library of Congress Catalogue Number TA658.44.A25

Contents

Preface

The purpose of the *Abstract Journal in Earthquake Engineering* is to organize annually a comprehensive collection of abstracts and citations from current earthquake engineering literature. The present volume contains abstracts of over 1000 research reports, technical papers, texts and reference books, codes and conference proceedings. The abstracts are drawn from 81 technical journals, and from the engineering, scientific and governmental publications of 23 countries and international organizations. The staff of the Journal acknowledges with sincere appreciation the efforts of the many individuals and organizations who have made valuable contributions to Volume 5.

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). This information program was established in 1971 as a joint project by the University of California at Berkeley and the California Institute of Technology. The NISEE program is supported by a public service grant from the National Science Foundation. The staff of the Earthquake Engineering Research Center at U.C. Berkeley is responsible for production of the Abstract Journal.

Availability of Abstracted Publications

Some of the abstracts have a dot (●) affixed to the immediate left of their Abstract Number. This indicates that the cited publication is a part of the collection of the EERC Library, 47th Street and Hoffman Boulevard, Richmond, CA 94804. These "dotted" publications may be borrowed from the library by residents of the United States, either by visiting the library or by telephone or mail request. In addition, photocopies of many of these publications may be obtained from the EERC Library. This service is available to any individual or organization regardless of location. In all cases please fully reference the desired matter, including the Abstract Number, and indicate whether you wish to borrow or purchase a photocopy of the publication. Details are available from the library at the above address.

NTIS Publications

Following the bibliographic citation for a number of abstracts is an NTIS accession number. Copies of these publications may be purchased from the National Technical Information Service, Springfield, Virginia 22161. Accession numbers should be quoted on all NTIS orders.

We wish to thank the many users who have commented on Volume 4. To assist us in further improving the Journal, we continue to welcome and encourage such constructive criticism and suggestions.

W. E. WAGY, General 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.

Beton i zhelezobeton
Structural Literature
Pr. Vladimirova 4, K-12
Moscow 103012
Union of Soviet Socialist Republics

Bibliography of Seismology
International Seismological Centre
6 South Oswald Road
Edinburgh, EH9 2HX, Scotland

Bollettino di Geofisica
Osservatorio Geofisico Sperimentale
34123 Trieste
Italy

*BUILD International**
Weena 700
Rotterdam, The Netherlands

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

*Bulletin of the Association of Engineering Geologists**
2570 Oakwood Manor Drive
Florissant, Missouri 63031

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

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 Transactions
The Institution of Engineers (Australia)
Science House
Gloucester & Essex Streets
Sydney, N.S.W.
Australia

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

Cuadernos del IIEA
Instituto de Investigaciones y Estudios Avanzados
Universidad de Guayaquil
Guayaquil, Ecuador

Earthquake Notes
Eastern Section
Seismological Society of America
E34-454, Lincoln Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02142

Emergency Planning Digest°
Emergency Planning Canada
Ottawa K1A 0W6
Canada

Engineering Geology°
Elsevier Scientific Publishing Co.
P.O. Box 211
Amsterdam, The Netherlands

Engineering Journal, AISC°
American Institute of Steel Construction
1221 Avenue of the Americas
New York, New York 10020

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
Great George Street
London, S.W. 1
England

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

Indian Concrete Journal
Concrete Association of India
Cement House
121 Maharshi Karve Road
Bombay 20
India

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

International Journal of Earthquake Engineering and Structural Dynamics°
John Wiley & Sons, Ltd.
Baffins Lane
Chichester, Sussex
England

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

International Journal of Fracture°
Noordhoff International Publishing
P.O. Box 26
Leyden, The Netherlands

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

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

International Journal for Numerical 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 the American Institute of Architects°
American Institute of Architects
1735 New York Avenue, N.W.
Washington, D.C. 20006

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

Journal of the Earth and Space Physics
Institute of Geophysics
University of Tehran
Amirabad, Tehran 14
Iran

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 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
Dunod-Gauthier-Villars
24-26, boulevard de l'Hopital
75005 Paris, France

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 Testing and Evaluation°
American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

Journal of Tsing Hua University and Peking University
Library
Tsing Hua University
Peking
People's Republic of China

Journal of the Waterways, Harbors and Coastal Engineering 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

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

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

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

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

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

Osnovania, fundamenty i mekhanika gruntov
Stroyizdat
Second Institutskaya Str., D.6
Moscow Zh-389
Union of Soviet Socialist Republics

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

Soils and Foundations
Japanese Society of Soil Mechanics and Foundation Engineering
Toa Bekkan Building
13-5 1-chome
Nishi-Shinbashi
Minato-ku
Tokyo, Japan

Stroitel'naya mekhanika i raschet sooruzhenii
Stroyizdat
Second Institutskaya Str., D.6
Moscow Zh-389
Union of Soviet Socialist Republics

The Structural Engineer°
Batiste Publications, Ltd.
Pembroke House
Campsbourne Road
Hornsey, London N8
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

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

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

1. General Topics and Conference Proceedings

1.1 General

● **1.1-1** **Progress report (September 1973–August 1974),** International Inst. of Seismology and Earthquake Engineering, Tokyo, Jan. 1975, 49.

The annual report from the IISEE describes the program of the institute. It is broken down into the following sections: (1) Constitution and membership of IISEE; (2) National liaison committee; (3) Curriculum committee; (4) External lectures; (5) List of participants; (6) Diary of training; (7) Schedule of lectures; (8) Subjects of lectures; (9) Trips for inspection; (10) Subjects of individual study; (11) Follow-up of ex-participants in India, Turkey and Iran; (12) Scientific papers by staff; (13) Books and journals; (14) Foreign seismological reports.

● **1.1-2** **Annual report 1973-74,** Seismographic Station, Univ. of California, Berkeley, Aug. 15, 1974, 21.

This annual report describes the main activities that occurred at the Seismographic Station during the year July 1973–June 1974. In particular, the research programs and activities are described.

● **1.1-3** Carney, J. M., **Bibliography on wood and plywood diaphragms,** *Journal of the Structural Division, ASCE,* **101,** *ST11,* Proc. Paper 11737, Nov. 1975, 2423–2436.

Since wood is becoming more important in structural design, and since many engineers are not familiar with its design, this bibliography was primarily prepared to assist the practicing engineer. Secondly, since the practice of diaphragm design is still developing, it also includes background and supplementary data for use by engineers and researchers. Abstracts are included to illustrate coverage and importance of the literature listed. A structural shear diaphragm is defined as a relatively thin building element in which the covering resists shear stresses, like the web of a deep beam, with perimeter members performing the function of flanges and stiffeners. Wood is becoming more important as a structural material for several reasons: (1) it is economical; (2) it is often more readily available than steel and concrete; (3) it requires less energy than either concrete or steel to convert it to usable form; and (4) it is our only naturally renewable construction material.

1.1-4 Poliakov, S. V., **The present state and major trends in new investigations into the earthquake resistance of buildings and structures** (Sovremennoe sostoyanie i osnovnye napravleniya novykh issledovanii v oblasti seismostoikosti zdanii i sooruzhenii, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 4,* 1975, 8–13.

A survey is given of various research projects in the theory and practice of earthquake engineering under way in research institutes of the U.S.S.R. during the Ninth Five-Year Plan. Lines of research in need of further development are pointed out.

● **1.1-5** **Earthquake Engineering Research Center Library printed catalog,** *EERC 75-12,* Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1975, 607. (NTIS Accession No. PB 243 711)

This report is the printed catalog of the Earthquake Engineering Research Center Library's holdings as of May 1975. The library was established in 1971 in response to the need for a special earthquake engineering reference library to serve both the professional and academic engineering communities. The library is one of the principal elements of the National Information Service for Earthquake Engineering, a joint public service program operated by the Earthquake Engineering Research Center of the Univ. of California, Berkeley and the California Inst. of Technology.

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

The library consists of an in-depth collection of materials from the wide range of subjects pertinent to earthquake engineering. At the time of the printing of this report, the holdings of the library consisted of over 7,000 technical journals, reports, conference proceedings, text, reference and other publications. The holdings also included collections of films, slides, photographs and maps.

Virtually all of the publications in the library are available either on loan or as photocopies. Information regarding this service can be found in the **Preface**.

● 1.1-6 Bolt, B. A. *et al.*, **Geological hazards: Earthquakes, tsunamis, volcanoes, avalanches, landslides, floods**, Springer-Verlag, New York, 1975, 328.

Growth of population, communication and interdependence among countries has sharpened the impact of natural disasters. Not only have calamities been given wider publicity, but the realization has grown that through rational study and foresight much can be done to mitigate these hazards to life and social well-being.

Earthquakes, faulting, tsunamis, seiches, volcanoes, floods, avalanches, rock and soil slides, differential settlement and soil liquefaction are examined in this account of worldwide geological hazards. The treatment is descriptive rather than mathematical. It is critical, and brings out some key controversies and alternative views on hazard control. Comparative case histories are drawn from many countries around the world.

1.2 Proceedings of Conferences

● 1.2-1 Pulmano, V. A. and Kabaila, A. P., eds., **Finite element methods in engineering**, Proceedings of the 1974 International Conference on Finite Element Methods in Engineering, Unisearch Ltd., Kensington, N.S.W., Australia, 1974, 840.

The conference was sponsored by and held at the School of Civil Engineering of the Univ. of New South Wales, Kensington, from Aug. 28–30, 1974. Of the 53 papers presented at the meeting, the following six are abstracted in this volume of the *AJEE*.

Finite element analysis of multilayer sandwich plates and shells, Khatua, T. P. and Cheung, Y. K.—*Finite element solution to some plane problems in soil dynamics*, Kameswara Rao, N. S. V. and Dasgupta, S. P.—*Finite element method and computer programs*, Ural, O.—*Finite element-perturbation analysis of nonlinear dynamic response of elastic continua*, Atluri, S. N.—*Finite element analysis of structural instability by association of pulsating excitations*, Cheng, F. Y.—*Analysis of buildings on elastic medium under dynamic or seismic loads*, Ovunc, B. A.

● 1.2-2 **Proceedings of the U.S. National Conference on Earthquake Engineering-1975**, Earthquake Engineering Research Inst., Oakland, June 1975, 661.

The first U.S. National Conference on Earthquake Engineering, sponsored by the Earthquake Engineering Research Inst. (EERI), was held at the Univ. of Michigan in Ann Arbor, June 18–20, 1975. In addition to the 58 papers presented at the conference, the proceedings also include major portions of the working drafts of five volumes of planning and field guides being developed by EERI. The purpose of the guides is to aid in establishing a methodology for maximizing the learning from destructive earthquakes. The five volumes are as follows: Vol. 1–Planning Guide; Vol. 2–Engineering Field Guide; Vol. 3–Geoscience Field Guide; Vol. 4–Social Science Field Guide; and Vol. 5–Special Topics. Portions of the guides which are omitted in the proceedings are noted in the text, and the complete contents of all volumes are included in Vol. 1, Appendix B. Information is given concerning the availability of the working drafts of Vol. 1.

All of the papers presented at the conference are abstracted in this volume of the *AJEE*; the following are the titles and authors' names:

Session I: *A deterministic approach to the prediction of free field ground motion and response spectra from stick-slip earthquakes*, Cherry, J. T., Halda, E. J. and Hamilton, K. G.—*Field measurement of relative ground displacement*, Donovan, N. C. and Degenkolb, H. J.—*A model for analysis of body and surface waves in strong ground motion*, Duke, C. M. and Mal, A. K.—*Measures of severity of earthquake ground shaking*, Housner, G. W.—*Earthquake hazard and confidence*, Chou, I. H. and Fischer, J. A.—*On the correlation of peak acceleration of strong motion with earthquake magnitude, epicentral distance and site conditions*, Trifunac, M. D. and Brady, A. G.—*Statistical uncertainty of design based on smoothed response spectra*, Donovan, N. C., Valera, J. E. and Beresford, P. J.—*Use of aftershock ground motion data in earthquake engineering*, Hays, W. W., Algermissen, S. T. and Duke, C. M.—*Design procedures, structural dynamics, and the behavior of structures in earthquakes*, Berg, G. V.—*Nationally-applicable seismic design recommendations - A progress report*, Sharpe, R. L. *et al.*—*Some problems and decisions relative to the response spectrum method of seismic design*, Zsutty, T.—*Seismic design criteria for structures and facilities—Trans-Alaska pipeline system*, Newmark, N. M.

Session II: *Causes, characteristics and effects of Puget Sound earthquakes*, Hawkins, N. M. and Crosson, R. S.—*Evaluation of existing buildings for seismic risk—A case study of Puget Sound Naval Shipyard, Bremerton, Washington*, Freeman, S. A., Nicoletti, J. P. and Tyrrell, J. V.—*Studies for seismic zonation of the San Francisco Bay* *region: A brief summary,* Borcherdt, R. D.—*Microzonation of Rocky Mountain states,* Liu, S. C. and De Capua, N. J.—*An experimental study of ground deformations caused by soil-structure interaction,* Luco, J. E., Trifunac, M. D. and Udwadia, F. E.—*Liquefaction, flow and associated ground failure,* Youd, T. L.—*A factor of safety approach for evaluating seismic stability of slopes,* Roth, W. and Lee, K. L.—*Transient two-dimensional analysis of soils by latticework,* Wylie, E. B., Streeter, V. L. and Papadakis, C. N.—*Seismic response of highway bridges,* Penzien, J., Chen, M.-C. and Tseng, W.-S.—*Seismic behavior of high curved overcrossings,* Williams, D. and Godden, W. G.—*Seismic response of a long multi-span highway bridge,* Baron, F. and Pang, S. H.—*Full scale, three-dimensional tests of structural deformations during forced excitation of a nine-story reinforced concrete building,* Foutch, D. A. *et al.*

Session III: *Correcting existing earthquake hazardous buildings in the city of Long Beach, California,* O'Connor, E. M.—*Reinforcing existing buildings to resist earthquake forces,* Lefter, J. and Colville, J.—*Building enclosure and finish systems: Their interaction with the primary structure during seismic action,* McCue, G. M. *et al.*—*Hysteretic behavior of steel columns,* Popov, E. P., Bertero, V. V. and Chandramouli, S.—*Characteristics of steel members and connections,* Hanson, R. D.—*Seismic response of a steel building frame,* Clough, R. W. and Tang, D.—*Earthquake tests of shear wall-frame structures,* Otani, S.—*Flexural properties of slender shear wall cross sections under monotonic loading,* Salse, E. A. B., Ghosh, S. K. and Fintel, M.—*Factors influencing the shear strength of beam-column joints,* Jirsa, J. O., Meinheit, D. F. and Woollen, J. W.—*Reversed cyclic loading behavior of reinforced concrete slab-column connections,* Hawkins, N. M., Mitchell, D. and Sheu, M. S.—*Hysteretic behavior of reinforced concrete flexural members with special web reinforcement,* Bertero, V. V. and Popov, E. P.—*How should we establish public policy on setting design codes or performance standards?,* de Neufville, R.

Session IV: *Nonstructural hospital systems in the earthquake environment,* Merz, K. L.—*Hospital design for earthquake performance: Vertical circulation,* Highlands, D., Oppenheim, I. and Strain, J.—*California's seismic safety for hospitals,* Meehan, J. F.—*Guidelines for evolution of lifeline earthquake engineering,* Duke, C. M. and Moran, D. F.—*Analysis of earthquake risk for lifeline systems,* Whitman, R. V., Cornell, C. A. and Taleb-Agha, G.—*Earthquake resistance of public utility systems - A report on findings of the California Governor's Interagency Earthquake Committee,* Iwan, W. D.—*Earthquake damage to water and gas distribution systems,* Katayama, T., Kubo, K. and Sato, N.—*Seismic soil-structure interaction of buried pipelines,* Parmelee, R. A. and Ludtke, C. A.—*Pipeline design to resist large fault displacement,* Newmark, N. M. and Hall, W. J.—*Seismic design of utility equipment anchors,* Townsend, W. H.—*Dynamic testing and seismic response analysis of pole-mounted electrical equipment,* Ibáñez, P., Smith, C. B. and Vasudevan, R.—*Lifeline simulation methods of modeling local seismic environment and equipment damage,* Schiff, A. J., Newsom, D. E. and Fink, R. K.

Session V: *Response of ground supported liquid storage tanks to seismic excitation,* Wu, C. I. *et al.*—*Evaluation of earthquake ground-motion characteristics at nuclear plant sites,* Werner, S. D.—*Seismic design criteria for nuclear powerplants,* Jennings, P. C. and Guzman, R. A.—*On static loads method for seismic design of nuclear power plant facilities,* Liao, E. N. and Marda, R. S.—*Observations on the process of equipment qualification,* Hall, W. J. *et al.*—*Comparative analysis of nuclear reactor control system design,* Russcher, G. E.—*Behavior of cracked concrete nuclear containment vessels during earthquakes,* Gergely, P., Stanton, J. F. and White, R. N.—*Floor response spectra of buildings with uncertain structural properties,* Chen, P. C.—*Seismic qualification by analysis of nuclear power plant mechanical components,* McDonald, C. K.—*The role of closely spaced modes in the seismic response of equipment and structures,* Nelson, F. C.

● **1.2-3 Abstracts of papers presented at the 46th Annual Meeting of the Eastern Section of the Seismological Society of America,** *Earthquake Notes,* **46,** *1-2,* Jan.–June 1975, 37–62.

The 46th Annual Meeting of the Eastern Section of the Seismological Society of America was held at the Hoffman Lab., Harvard Univ., Cambridge, Massachusetts, Oct. 10–11, 1974. In addition to the abstracts of the papers presented at the meeting, an author index is contained in this issue. The following are the titles, authors' names and page numbers (in parentheses) of those abstracts relevant to earthquake engineering. These abstracts are not included in this volume of the *AJEE.*

Comparison of strong ground motion from several dislocation models, Anderson, J. (37)—*Ground motion in the vicinity of a propagating thrust fault,* Niazy, A. (38)—*The relationship between teleseismic P-wave and near-field strong motion observations for the 9 February 1971, San Fernando earthquake,* Langston, C. A. (39)—*Ratio of P and S wave spectra and implications for models of earthquakes,* Rautian, T. G., Khalturin, V. I. and Molnar, P. (40)—*Interpretation of strong-motion earthquake accelerograms: The Bear Valley event of 1973,* Turnbull, Jr., L. S. and Battis, J. C. (41)—*A three-dimensional dislocation model for the Bear Valley, California, earthquake of 27 June 1973,* Trifunac, M. D. (42)—*Modeling local earthquakes as shear dislocations in a layered halfspace,* Helmberger, D. V. (42)—*The Quebec-Maine border earthquake of June 15, 1973,* Wetmiller, R. (44)—*The Georgia-*

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

South Carolina earthquake of 2 August 1974; foreshock survey and macroseismic effects, Long, L. T. and Denman, H. E. (45)—*Aftershock studies following the 2 August 1974 South Carolina earthquake,* Talwani, P. *et al.* (46)—*Some preliminary results from a seismograph network in the New Madrid, Missouri region,* Zollweg, J. *et al.* (46)—*A study of occurrence probabilities of earthquake in the southern New England area,* Shakal, A. F. (47)—*Microearthquakes near Chiang Mai, Thailand,* Bufe, C. G. and Willis, D. E. (48)—*Seismicity, earthquake mechanisms and tectonics of Burma, 20°N-28°N,* Chandra, U. (48)—*Global frequency-magnitude relationships and their implications,* Chinnery, M. A. and North, R. G. (55)—*Spectral analysis of earthquake occurrence rates,* Landers, T. and Chinnery, M. A. (55)—*Tidal triggering of earthquakes,* Heaton, T. H. (56)—*Triggering of deep focus earthquakes by precursive shocks,* Strelitz, R. A. (56)—*Properties of cracked solids and precursory velocity changes,* O'Connell, R. J. and Budiansky, B. (57)—*Cyclical stress accumulation on a strike-slip fault,* Turcotte, D. L. (57)—*Co-seismic strain steps along San Andreas Fault,* King, C.-Y., Nason, R. D. and Burford, R. O. (58)—*Modification of seismic waves by a building,* Cloud, W. K. (59).

● **1.2-4 Abstracts of papers presented at the 70th Annual Meeting of the Seismological Society of America,** *Earthquake Notes,* **46,** *3,* July-Sept. 1975, 3-53.

This entire issue is devoted to abstracts of papers presented at the 70th Annual Meeting of the Seismological Society of America, held at California State Univ., Los Angeles, Mar. 25-27, 1975. An author index also is included. The following are the titles, authors' names and page numbers (in parentheses) of those abstracts relevant to earthquake engineering; these abstracts are not contained in this volume of the *AJEE.*

Identification of structures through records obtained during strong earthquake ground motion, Udwadia, F. E. (3)—*Seismicity studies using sonobuoy hydrophones and ocean bottom seismographs,* Brune, J. *et al.* (4)—*Increased fault creep and water flooding at the Buena Vista thrust fault, California,* Nason, R. D. (4)—*Geodetic measurement of deformation in Owens Valley, California,* Savage, J. C., Church, J. P. and Prescott, W. H. (5)—*Earthquake swarms and the semidiurnal solid earth tide,* Klein, F. W. (6)—*Rayleigh wave phase velocities across the Eurasian continent,* Patton, H. J. (6)—*Deformation in the Transverse Ranges, California, determined from a dislocation model of the San Andreas Fault,* Rodgers, D. A. (8)—*A source theory for complex earthquakes,* Blandford, R. R. (9)—*Duration as a measure of seismic moment and magnitude: An insight as to why it works,* Herrmann, R. B. (10)—*A note on the calculation of Fourier amplitude transforms,* Udwadia, F. E. and Trifunac, M. D. (14)—*Two-dimensional, antiplane, building-soil-building interaction for two or more buildings and for incident plane SH-waves,* Wong, H. L. and Trifunac, M. D. (15)—*A deterministic approach to the prediction of free field ground motion and response spectra from stick-slip earthquakes,* Cherry, J. T., Halda, E. J. and Hamilton, K. G. (15)—*Experimental dynamic of highway bridges by quick-release pull testing,* Douglas, B. M. (16)—*A method for calculating nonlinear seismic response in two dimensions,* Joyner, W. B. (16)—*Observation of 1- to 5-sec microtremors and its application to earthquake engineering problems,* Ohta, Y. and Goto, N. (17)—*Attenuation of peak acceleration in earthquakes,* Tocher, D. and Patwardhan, A. S. (18)—*Characteristics of 3-dimensional earthquake ground motions,* Penzien, J. and Watabe, M. (18)—*Seismic considerations in siting large underground openings in rock,* Glass, C. E., Brekke, T. L. and Taylor, R. L. (19)—*Simplified procedures for estimating the fundamental period of a soil profile,* Oweis, I., Dobry, R. and Urzua, A. (19)—*Estimating response spectra from peak values of ground motion,* Brady, A. G. (20)—*A study of ground motion amplification in Salt Lake City, Utah,* Harding, S. T., Rogers, A. M. and King, K. (21)—*A comparison of linear and pseudo non-linear methods of site response analysis,* Lew, M. and Campbell, K. W. (21)—*Distribution of earthquake damage in Long Beach in 1933 as related to propagation and site effects,* Campbell, K. W. (22)—*In situ measurements of seismic velocities in the San Francisco Bay region,* Gibbs, J. F. *et al.* (22)—*Surface wave contributions to strong ground motion,* Swanger, H. J. and Boore, D. M. (23)—*A study on the duration of strong earthquake ground motion,* Trifunac, M. D. and Brady, A. G. (24)—*On the correlation of seismoscope response with earthquake magnitude and Modified Mercalli intensity,* Trifunac, M. D. and Brady, A. G. (24)—*Effect of self-induced axial forces in the seismic response of buildings,* Paz, M. and Wong, J. P. (24)—*A study of strong ground motion from a set of Peruvian earthquakes and their relation to damage,* Husid, R. and Espinosa, A. F. (25)—*Recent development on in-situ measurement of shear wave velocities in Japan for elucidating ground characteristics during an earthquake,* Goto, N. and Ohta, Y. (25)—*Statistical determination of second order moment of earthquake sequences,* Kagan, Y. (26)—*Short term variations in the level of global seismic activity,* Chinnery, M. A. and Landers, T. E. (26)—*Modulation of seismicity by atmospheric torques,* Bostrom, R. C. (28)—*Earthquake recurrence predictions for western North America,* Howell, Jr., B. F. (28)—*Seismicity of San Diego, 1934-1974,* Simons, R. S. (29)—*Seismicity, earthquake mechanism and tectonics along the Himalayan Mountain range,* Chandra, U. (29)—*Dynamic interaction of seismic activity along rising and sinking edges of Indian and Pacific Ocean plate boundaries,* Berg, E., Sutton, G. H. and Walker, D. A. (30)—*A study of foreshocks in central California,* Kodama, K. P. and Bufe, C. G. (30)—*Seismicity of central coastal California,* Gawthrop, W. H. (31)—*1974 Lima, Peru accelerograph records,* Knudson, C. F. and Perez, V. (31)—*Damage effects and strong motions due to the Lima, Peru, earthquake of October 3, 1974,* Husid, R. *et al.* (31)—*Hazard*

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

maps, risk maps and zoning maps for use by seismologists, engineers and public agencies, Algermissen, S. T. (32)—*Seismological and geological data available to earthquake engineers,* Allen, C. R. (32)—*Stable parameters for the characterization of strong ground motion,* Bolt, B. A. (33)—*The characteristics of strong ground motion as revealed by accelerograph records,* Hudson, D. E. (33)—*Earthquake considerations in the design of hospitals under the new requirements in California,* Jephcott, D. K. (33)—*Establishment of earthquake design criteria for hospital facilities in the U.S.,* Johnston, R. G. (34)—*Practical design of building structures to resist earthquakes,* Johnston, S. (34)—*Establishing earthquake engineering design criteria,* Newmark, N. M. (34)—*Establishing design earthquakes in the central United States,* Nuttli, O. W. (35)—*Assessment of earthquake hazards for special projects,* Page, R. A. (35)—*The role of soils in earthquake engineering,* Seed, H. B. (35)—*Studies of recent displacements along the Denali Fault, south-central Alaska,* Sieh, K. E. and Cluff, L. S. (36)—*Short-term anomalous tilting prior to earthquakes in southern California,* Buckley, C. P. *et al.* (37)—*The Lima earthquake of October 3, 1974—Intensity distribution and strong motion records,* Espinosa, A. F. *et al.* (37)—*The Lima, Peru 1974 earthquake series,* Spence, W. *et al.* (38)—*Acceptable risk in seismic safety elements in California general plans,* Asquith, D. O. (39)—*Earthquake magnitude as a function of intensity data in California and western Nevada,* Toppozada, T. R. (39)—*Seismic safety study: City of Los Angeles,* Wiggins, J. H. and Lee, L. T. (40)—*Strong motion displacement field measured from a foam rubber model of strike-slip faulting,* Archuleta, R. J. and Brune, J. N. (42)—*Attenuation of high frequency strong ground motion,* Berrill, J. B. and Hanks, T. C. (43)—*A broad look at strong-motion parameters as revealed by the data for the period of 40 years of strong-motion programs in the western United States,* Trifunac, M. D. (44)—*Effects of canyon topography on strong ground motion,* Wong, H. L. and Jennings, P. C. (44)—*Simulation of site related earthquake motions,* Lou, Y. S. and Lepore, J. A. (45)—*A search for seismic precursors of the Hollister earthquake of November 28, 1974,* Lee, W. H. K. and Healy, J. H. (46)—*An explosion source model for tuff,* Peppin, W. A. (46).

1.2-5 **Program of the 90th Meeting of the Acoustical Society of America,** *The Journal of the Acoustical Society of America,* 58, *Supplement No. 1,* 1975, var. pag.

The 90th meeting of the ASA was held in San Francisco, Nov. 3-7, 1975. This supplemental issue contains abstracts of papers presented at the meeting. The following eight abstracts pertain to earthquake engineering. The numbers in parentheses are paper numbers. These abstracts are not included in this volume of the *AJEE.*

Structural damping from random data (N5), Abrahamson, A. L.—*Modal damping determinations from resonance spectral shape measurements* (N6), Douglas, B. E.—*Physics of vibrators* (W1), Skudrzyk, E. J.—*Natural frequencies of elastically supported orthotropic rectangular plates* (W2), Magrab, E. B.—*Vibrations of a circular plate elastically restrained along the edge and carrying a concentrated mass* (W3), Laura, P. A. A., Luisoni, L. E. and Arias, A.—*Iterative solution for random vibration problems involving structure-fluid interaction* (W5), Lin, Y. K.—*Numerical-perturbation technique for the transverse vibrations of highly prestressed plates* (W6), Nayfeh, A. H. and Kamat, M. P.—*Vibration response of a fluid-loaded infinite plate with symmetric or asymmetric stiffeners* (W7), Vogel, W. H. and Feit, D.

● 1.2-6 **Seminar on construction in seismic regions and in regions with difficult ground conditions,** Committee on Housing, Building and Planning, United Nations Economic Commission for Europe, Bucharest, Oct. 14-18, 1974, 232.

This seminar was held at the initiation of the Romanian government in Bucharest, Oct. 14-18, 1974. Monographs were submitted by Bulgaria, Finland, France, Hungary, Spain, Sweden, the Union of Soviet Socialist Republics, the United Kingdom, the United States and Yugoslavia. The contents are as follows; none of the reports or papers are abstracted in this volume of the *AJEE*:

Subject A: Design, Construction and Control of Buildings to be Erected in Seismic Areas: Vol. I, Part 1: *Review of problems and policies for Europe,* prepared by Romania—Part 2: *Design, construction, control and maintenance of buildings in seismic regions in the United States,* prepared by the United States—Vol. II: *Main policy issues for discussion at the seminar,* prepared by Romania and the United States.

Subject B: Design, Construction and Control of Buildings to be Erected in Areas with Difficult Ground Conditions: *Introductory report,* prepared by France—*Introductory report,* prepared by the U.S.S.R.—*International cooperation to improve methods of design and construction of buildings to be erected in seismic regions and in regions with difficult ground conditions,* prepared by Bulgaria.

Research Papers: *Behaviour under seismic action of monolith and precast framed dwelling structures,* Diaconu, D. *et al.*—*Some researches concerning the extension of employing great panel structures located in seismic areas,* Diaconu, D. *et al.*—*Some directions of international cooperation in earthquake engineering research,* Sandi, H. and Serbanescu, G.

● 1.2-7 **Preprints, 1974 Offshore Technology Conference,** Offshore Technology Conference, Dallas, May 1974, 2 vols., 2094.

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

The Sixth Annual Offshore Technology Conference was held in Houston, May 6–8, 1974. The conference was sponsored by the Offshore Technology Conference (OTC) on behalf of nine organizations. The two preprint volumes contain 183 papers; in addition, an alphabetical subject index and an author index are included. OTC does not plan to publish the conference papers in any other form.

The following four papers of interest to earthquake engineers are abstracted in this volume of the *AJEE: Dynamic random analysis of fixed offshore platforms,* Mansour, A. E. and Millman, D. N.—*Three-dimensional stochastic response of offshore towers to wave forces,* Berge, B. and Penzien, J.—*Field testing of laterally loaded piles in sand,* Cox, W. R., Reese, L. C. and Grubbs, B. R.—*Analysis of laterally loaded piles in sand,* Reese, L. C., Cox, W. R. and Koop, F. D.

● 1.2-8 **Proceedings, Fifth European Conference on Earthquake Engineering,** Earthquake Research Inst., Turkey, Ministry of Reconstruction and Resettlement, Ankara, Sept. 22–25, 1975, 2 vols., 1382.

The Fifth European Conference on Earthquake Engineering was held in Istanbul, Sept. 22–25, 1975. The 167 papers presented at the conference are listed below. Due to scheduling and publication constraints, it was not possible to include an abstract of every paper in this volume of the *AJEE.* Abstracts are included only for those papers that have an asterisk following the title.

Volume 1

Chapter 1: Engineering Seismology: *In-progress seismic monitoring at a nuclear power plant site,** Severy, N. I. *et al.*—*An intensity scale for earthquakes,* Mortgat, C. P. and Shah, H. C.—*Characteristics of earthquake intensity,* Hoshiya, M., Kusano, N. and Ishii, K.—*The variation of the frequency content of earthquake accelerograms,** Joannon, J. G., Arias, A. and Saragoni, G. R.—*Relation between macroseismic effect and ground vibration velocity,* Medvedev, S. V., Nersesov, I. L. and Bune, V. I.—*Seismic microzoning of Banja Luka urban area,* Stojkovic, M.—*Establishment of strong motion network in Yugoslavia,** Mihailov, V. and Kirijas, T.—*Proposed methods for data processing of strong motion acceleration measurements in Yugoslavia,* Petrovski, D.—*Maximum values of the particle velocities produced by explosive sources and their properties,* Schenk, V.—*On the estimation of the earthquake intensity using macroseismic observations of buildings with antiseismic amplification,** Martemyanov, A. I. and Shirin, V. V.—*On the intensity of strong motion earthquakes,* Poçeski, A.—*Modelling of seismic action by explosions,** Karapetian, B. K., Karapetian, N. K. and Mekhitarian, L. A.—*Quantitative determination of earthquake intensity,** Nazarov, A. G. *et al.*—*Effect of groundwater and relief on seismicity of soils,* Napetvaridze, Sh. G., Jabauri, G. G. and Gogelia, T. I.—*Analysis of seismic waves in the period range of 1 to 10 seconds,** Büyükaşikoglu, S.

Chapter 2: Dynamics of Soils and Soil Structures: *A geodynamical evaluation of the Elbistan power plant site,** Soydemir, C. and Gürpinar, A.—*Empirical liquefaction index for sands,** Nunnally, S. W., Krizek, R. J. and Edil, T. B.—*The damping characteristics of cohesive soils determined experimentally,** Kumbasar, V. and Erguvanli, A.—*Propagation of shear stress waves in layered media,** Martincek, G.—*Power spectrum representation of earthquake motions,** Gürpinar, A.—*Effects of soil conditions during earthquakes,* Kogan, L. A. and Giller, V. G.—*Torsional vibration of structure due to obliquely incident SH waves,** Kobori, T. and Shinozaki, Y.—*Behaviors of the alluvial layers on the sloped bed rock during earthquakes,** Hamada, M. and Fujita, H.—*Earthquake response of continuous media using dynamic relaxation,* Naumovski, N. and Petrovski, D.—*Relation between long-period microtremors and the underground structure,** Allam, A.—*Dynamic shear properties of sand,** Miladinov, D. *et al.*—*Relative stiffness and damping capacity of soils,** Kuribayashi, E., Iwasaki, T. and Tatsuoka, F.—*Dynamic passive earth pressure distribution in retaining walls,* Saran, S. and Prakash, S.—*Longitudinal waves in sand specimens and stress-strain relationships,** Capecchi, A. and Conti, G.—*An experimental investigation of seismic effects on the bearing capacity of soils,* Stavnitser, L. R. and Karpenko, V. P.—*A method to diminish the settling of buildings in seismic regions,* Korcinski, N. and Ieremia, M.—*Hysteretic damping of a soil-structure system for determination of modal damping,** Sotirov, P.—*The calculation of soil-dynamic parameters based on a general rheological model of the subsoil,* Langer, M.—*A parametric study of soil amplification,** Finn, W. D. L., Tezcan, S. S. and Ipek, M.

Chapter 3: Foundations and Soil Structure Interaction Problems: *Soil amplification survey for the Sogutlucesme viaducts, Istanbul,** Tezcan, S. S. and Durgunoglu, H. T.—*Earthquake analysis of Keban Dam,** Akay, H. U. and Gülkan, P.—*Seismically induced settlements,** Nataraja, M. S.—*An application of finite element method to soil-foundation interaction analyses,** Kuribayashi, E. and Iida, Y.—*Finite element grids for dynamic response analysis,** Dezfulian, H.—*Dynamic-frame foundation interaction,* Dumanoglu, A. and Severn, R. T.—*Behavior of underground tanks during earthquakes,** Hamada, M., Izumi, H. and Omori, K.—*Torsional response of embedded circular foundations,** Stokoe, II, K. H. and Erden, S. M.—*Evaluation of soil structure interaction parameters from dynamic response of embedded footings,** Petrovski, J.—*The seismic response of soil foundation structure systems,** Ionescu, C. *et al.*—*Influence of soil-structure interaction on the dynamic response of structures,** Petrovski, J.—*The soil-structure interaction and the soil amplification phenomenon,** Ionescu, C. D. and Barbat, H.—*Analysis of embank-*

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

ment profile changes under seismic impact,° Birbrayer, A. N.—*Seismic analysis of a rockfill dam,*° Vulpe, A. *et al.*—*Dynamic behavior of a subsurface tubular structure,*° Kuribayashi, E., Iwasaki, T. and Kawashima, K.—*Application of the theory of wave propagation to the analysis of buildings under earthquakes,* Bobakov, L. N.—*Seismic stability of massive structures,* Malyshev, L. K. and Shulman, S. G.—*Estimates of non-synchronous seismic disturbances,* Sandi, H.—*Behaviour of pile foundations under horizontal seismic action,*° Grib, S. I.—*Consideration on resistant dams in seismic areas,* Moroianu, A. and Mihalcea, A.—*Static and dynamic test of piles under horizontal load,*° Petrovski, J. and Jurukovski, D.—*Vibration of soil-supported foundations,*° Mirza, W. H.—*A prediction of earth dam response during earthquakes,*° Seleznev, G. S., Zaslavskij, J. L. and Tschalkina, G. I.

Chapter 4: Response of Structures: *Response of some structures in the nonelastic stage,*° Brankov, G., Sachanski, S. and Paskaleva, I.—*Analysis of structures subjected to horizontal and vertical earthquake,*° Ovünç, B. A.—*Elastic-plastic systems excited by non-stationary random vibrations,*° Müller, F. P. and Henseleit, O.—*A study of dynamic interaction in a plate-reservoir system,* Finn, W. D. L. and Varoglu, E.—*The comparative seismic response of some eleven-levelled structures of monolith and precast frames,* Diaconu, D. *et al.*—*Response of structures to propagating ground motions,*° Veletsos, A. S., Erdik, M. O. and Kuo, P. T.—*Response of strained structures to time-phased seismic excitations,*° Paz, M. and Wong, J.—*Upper bound of response spectrum,* Hoshiya, M., Shibata, S. and Nishiwaki, T.—*On the ductility of prestressed normal and lightweight concrete bent members,*° Negoita, A. and Dumitraş, M.—*Dynamic properties of some modern building systems,*° Rosman, R.—*Dynamic unstability of the framed systems under the seismic loading,*° Juhásová, E.—*Inelastic response of arches under earthquake motions,*° Thakkar, S. K. and Arya, A. S.—*On some uniqueness problems in building systems identification from strong motion records,*° Udwadia, F. E.—*Dynamic behaviour of liquid filled circular cylindrical shells,*° Aktaş, Z. and Uluç, F.—*Behaviour of yielding soft-storey structures,*° Pekau, O. A.—*A large displacement seismic analysis of monodimensional elastic structures,*° Benvenuto, E. *et al.*—*Changing over system of seismic structural protection,* Eisenberg, J. M.—*Non-linear parametrical problems in the theory of seismic structures,* Nickolaenko, N. A. *et al.*—*Dynamic behaviour of complex structural systems,*° Sotirov, P., Tzenov, L. and Boncheva, H.—*An approximate method of lateral load analysis for multi-story shear wall structures,* Celebi, M. and Citipitioglu, E.—*Contribution to earthquake analysis of coupled shear walls,*° Rutenberg, A. and Tso, W. K.—*Numerical analysis of multistorey structures,*° Fajfar, P.—*Use correlative dependence between accelerations in design,*° Medvedeva, E. S.—*On the mean-square dynamic stability of some elastic systems,*° Kisliakov, S.—*Seismic stability of the supporting structure for a spherical tank, volume 2000*m^3, Kapsarov, H.—*Influence of properties and stressed state of systems on structures' response,*° Aliev, G. *et al.*—*Analysis of earthquakeproofness of thin-walled spatial systems,* Nemtchinov, Y. I. *et al.*—*Response of complex structures to seismic motion,*° Kartsivadze, G. N. and Chachava, T. N.—*Seismic behaviour of structures with taper,*° Pekau, O. A.—*Seismic effects on rheologically non-homogeneous structures,* Sandi, H.—*Interaction between a hydraulic structure and water during earthquakes,* Gordeeva, S. P. and Shulman, S. G.

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Chapter 5: Dynamic Tests of Models and Structures: *Analytic and experimental hysteretic loops for R/C subassemblages,*° Popov, E. P., Bertero, V. V. and Viwathanatepa, S.—*Earthquake test behavior of a two-story reinforced concrete frame,*° Hidalgo, P. and Clough, R. W.—*Earthquake-resistant properties of reinforced concrete columns,*° Tanaka, Y. *et al.*—*Laboratory tests of shear walls for multi-story buildings,*° Corley, W. G.—*The beam-column joint: An important element in the seismic response of moment resisting steel frames,*° Krawinkler, H., Bertero, V. V. and Popov, E. P.—*Behaviour of joints and ductility of reinforced concrete frames,*° Uzümeri, S. M. and Seçkin, M.—*Repaired beam-column subassemblages subjected to earthquake type loads,*° Lee, D. L. N., Wight, J. K. and Hanson, R. D.—*Types of jointings at large-panelled fabricated constructions in seismic regions,* Mazilu, P. *et al.*—*Effects of history on biaxial resistance of a R/C section,*° Aktan, A. E.—*Modelling and identification of nonlinear dynamic behavior of steel frames,*° Distefano, N. and Salmonte, A.—*Nonelastic behaviour of some structural elements,*° Paskaleva, I.—*Inelastic cyclic behavior of reinforced concrete columns,*° Atalay, B. and Penzien, J.—*Formulation of mathematical model of a multistory building, based on the full-scale experiments,*° Taskovski, B., Paskalov, T. and Petrovski, J.—*Damping of large-panel buildings,*° Pollner, E. and Groper, M.—*Research into gravity seismic isolating system by means of modeling and full scale test,* Izenberg, Ya. M. *et al.*—*The experimental study of hysteretic characteristic of braced frames,* Suzuki, T. *et al.*—*Physical model test problems of structural seismic stability,*° Malyshev, L. K. and Monakhenko, D. V.—*Modelling of hydraulic structures subjected to seismic loads,*° Monakhenko, D. V.—*Vibration of prestressed concrete in the cracking phases,*° Balint, E.—*Destructive test of a 4-story concrete structure,*° Czarnecki, R. M., Freeman, S. A. and Scholl, R. E.—*Investigation non-linear behavior of carcassless buildings with powerful vibration generators,* Ashkinadze, G., Zacharow, W. and Simon, J.—*Model studies of earthquake resistance of masonry buildings,*° Oganessian, N. L. *et al.*—*Behaviour of some members and joints made up of resistive lightweight concrete compared to heavy concrete ones, under static and dynamic loadings,*° Mihai, C. *et al.*—*Interaction between partially jointed structural units,* Jurukovski, D.—*Stiffness*

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

deterioration of cyclic loaded reinforced concrete structural elements,° Anicic, D. and Zamolo, M.—*Dynamic characterizations for multistoreyed buildings with central core and hanged slabs,* Apostolov, G.—*Structure of an antiseismic skeleton frame with three-axis compression,*° Kligerman, S. I. and Medvedyev, M. I.—*Influence of infill walls on the earthquake response of framed structures,* Ciongradi, C. and Ciongradi, I.—*Improvement of vibration (resonance) test methods for buildings,* Ashkinadze, G. and Simon, J.—*Earthquake resistance of prestressed reinforced concrete,* Zhunusov, T.—*Analysis by means of physical models of the seismic behaviour of conrete arch dams,* Oberti, G., Castoldi, A. and Mazzieri, C.—*Investigating the earthquake resistance of multistory reinforced concrete buildings,*° Badalian, R. A. *et al.*

Chapter 6: Earthquake Resistant Design: *A study on the earthquake resistant design of subaqueous tunnels,* Tamura, C. and Okamoto, S.—*The development of dynamic design of buildings in Japan,* Umemura, H.—*Fundamental concept of aseismic design of underground piping system,* Kubo, K.—*Design earthquake selection and design criteria for nuclear components,*° Lou, Y. S. and Lepore, J. A.—*Engineering-seismometric information in earthquake resistant structural design,* Poliakov, S. V. *et al.*—*Protection of essential mechanical equipment in seismic areas,*° Yanev, P. I. and Gönen, B.—*Buildings on springs to resist earthquakes,*° Derham, C. J., Learoyd, S. B. B. and Wootton, L. R.—*Inelastic behavior of shear wall-frame systems estimated by the finite element method,* Yüzügüllü, O.—*Simplifying considerations on the aseismic design of shear structures,* Carydis, P. G., Vagelatou-Nikolaidou, O.—*Use of ductility factors in aseismic design,*° Mahin, S. A. and Bertero, V. V.—*Do we need design response spectra,*° Papastamatiou, D. J.—*Limit state analysis and synthesis of seismic design,* Kilimnik, L. Sh., Zharov, A. M. and Burgman, I. N.

Chapter 7: Recent Destructive Earthquakes: *A new method of earthquake damage analysis for industrial facilities and its application to the cases of recent earthquakes in Japan,*° Hara, F.—*Structural reparations of damaged buildings Caracas earthquake of July 29, 1967,* Arcia R., J. and Malaver R., A.—*The Akkum Building during the February 1, 1974 Izmir earthquake and its repair,*° Celebi, M. and Gülkan, P.—*Bandar-E-Abbas (Iran) earthquake of November 8, 1971,* Moinfar, A. A. and Banisadr, M.—*Seismological and engineering aspects of the March 6, 1974 Carazo earthquake (Nicaragua),* Husid, R. and Espinosa, A. F.—*Leukas earthquake of November 4, 1973, Greece,* Roussopoulos, A. A.—*Studies on damage pattern in some recent Indian earthquakes,* Guha, S. K. *et al.*—*Some engineering aspects of Managua earthquake of December 1972,*° Moinfar, A. A.—*Seismological and engineering features of the October 3, 1974, Lima, Peru earthquake,* Espinosa, A. F., Husid, R. and Algermissen, S. T.

Chapter 8: Low Cost Housing and Prefabricated Structures: *Some structural solutions of buildings with walls of brick and natural stone and large-panel buildings for mass construction in seismic regions,* Poliakov, S. V.—*Designing and construction of stone-frame buildings,* Izmailov, U. V. and Chuprina, A. A.—*Box-unit dwelling houses in seismic-resistant construction,* Bukharbaev, T. H., Paramzin, A. M. and Itskov, I. E.—*Cooperative research on full scale prefabricated buildings conducted by IZIIS, University Kiril & Metodij, Skopje and U. C. Berkeley,*° Petrovski, J., Jurukovski, D. and Bouwkamp, J. G.—*Big compound blocks of natural stone with prestressed reinforcement,* Izmailov, Yu. V., Il'Chenko, E. V. and Tarnovsky, K. I.

Chapter 9: Earthquake Response of Bridges: *Analytical modeling for seismic studies of extended bridge structures,*° Baron, F. and Pang, S.-H.—*Seismic characteristics of long multi-span highway bridge types,*° Baron, F., Hamati, R. E. and Pang, S.-H.—*Reconstruction and comparative forced vibration studies of the Stone Arch Bridge in Skopje,*° Velkov, M. and Jurukovski, D.—*Some problems in counterplans to earthquake on new high speed railway lines,* Fujiwara, T.—*Response of highway bridges under dynamic load,* Rajanna, B. C. and Munirudrappa, N.—*Forced vibration survey of Istanbul Bogazici suspension bridge,*° Tezcan, S. S. *et al.*

Chapter 10: Seismic Risk and Optimization: *Optimum resource allocation in earthquake engineering,* Rosenblueth, E.—*A study of seismic risk for Nicaragua,*° Shah, H. C. *et al.*—*Procedures and confidence limits for earthquake hazard studies,*° Fischer, J. A. and Chou, I. H.—*Seismic risk analysis-California state water project,* Shah, H. C. and Movassate, M.—*Probability distribution of earthquake accelerations for sites in western Germany,* Ahorner, L. and Rosenhauer, W.—*Seismotectonic parameters as a basis for seismic risk evaluation,*° Schneider, G.—*Migration of destructive earthquakes in Middle America and associated risk of occurrence,* Grases G., J.—*Seismic risk study of Izmir,*° Gülkan, P. and Yücemen, M. S.—*Determination of the optimal structural system for seismic regions,* Brankov, G. and Boncheva, H.—*A methodology for efficient and reliable design of high-rise structures under dynamic loads,*° Kamil, H. and Bertero, V. V.—*Input-output relations in the optimization of seismic protection,*° Benedetti, D. and Vitiello, E.—*Optimum siting in seismic regions,*° Kunar, R. R.—*A mathematical model of a single story earthquake resistant steel frame,*° McNiven, H. D. and Matzen, V. C.—*Optimum arch dam shape definition for earthquake load,* Bickovski, V. and Petrovski, J.—*Optimal height of tall buildings under seismic loading,* Tzenov, L. and Baltov, A.

● **1.2-9 Proceedings, 1975 Offshore Technology Conference,** Offshore Technology Conference, Dallas, May 1975, 3 vols., 2785.

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

The Seventh Annual Offshore Technology Conference was held in Houston, May 5–8, 1975. The conference was sponsored by the Offshore Technology Conference on behalf of nine organizations. In addition to three volumes of papers, an alphabetical subject index and an author index are included. Fifteen of the 245 papers presented at the meeting are pertinent to earthquake engineering and are abstracted in this volume of the *AJEE*. The following are the titles and authors' names:

Buckling and post-buckling strength of circular tubular sections, Bouwkamp, J. G.—*Comparison between predicted and experimentally determined low cycle fatigue life of welded tubular connections*, Maison, J. R. and Holliday, G. C.—*Fatigue behavior of tubular joints in offshore structures*, Mukhopadhyay, A., Itoh, Y. and Bouwkamp, J. G.—*Dynamic analysis of the North Sea Forties Field platforms*, Gray, R. M., Berge, B. and Koehler, A. M.—*Application of spectral methods to non-linear dynamic systems*, Filson, J. J. and Perez y Perez, L.—*Field testing and analysis of laterally loaded piles in stiff clay*, Reese, L. C., Cox, W. R. and Koop, F. D.—*Seismic risk analysis for offshore structures*, Cornell, C. A. and Vanmarcke, E. H.—*Seismic analysis of platform structure-foundation systems*, Penzien, J.—*Probabilistic response of offshore platforms to seismic excitation*, Hasselman, T. K., Bronowicki, A. and Chrostowski, J.—*Evaluation of seismicity and earthquake shaking at offshore sites*, Page, R. A.—*Soil response considerations in seismic design of offshore platforms*, Idriss, I. M., Dobry, R. and Power, M. S.—*Earthquake response spectra for offshore structures*, Kirkley, O. M. and Murtha, J. P.—*Inelastic analysis of fixed offshore platforms for earthquake loading*, Kallaby, J. and Millman, D. N.—*Stochastic dynamic response analysis of offshore platforms, with particular reference to gravity-type platforms*, Moan, T., Haver, S. and Vinje, T.—*Application of concrete drilling and production caissons to seismic areas*, Gerwick, Jr., B. C.

● **1.2-10 Abstracts of papers presented at the 47th Annual Meeting of the Eastern Section of the Seismological Society of America**, *Earthquake Notes*, **46**, *4*, Oct.-Dec. 1975, 41-65.

The 47th Annual Meeting of the Eastern Section of the Seismological Society of America was held in St. Louis at St. Louis Univ. on Nov. 6–7, 1975. In addition to the abstracts of the papers presented at the meeting, an author index is included in this issue. The following abstracts are pertinent to earthquake engineering; they are not included in this volume of the *AJEE*. The number in parentheses refers to the page number on which the abstract appears.

A seismic trigger for real-time warning local tsunami potentiality: One per hundred years, Adams, W. M. *et al.* (41)—*Source properties of a Blue Mt. Lake earthquake*, Anderson, J. G. and Fletcher, J. B. (43)—*Additional data on the seismicity of Hawaii*, Furumoto, A. S. (46)—*Attenuation of intensities based on isoseismals of earthquakes in central U.S.*, Gupta, I. N. (46)—*A detailed study of the June 13, 1975 New Madrid seismic zone earthquake*, Herrmann, R. B. *et al.* (47)—*Seismic siting procedures for nuclear power plants*, Hofmann, R. B. (47)—*On earthquake size*, Howell, Jr., B. F. (48)—*Study of attenuation from the 1975 Pocatello Valley, Idaho, earthquake*, King, K. W. and Ellison, D. M. (49)—*The 1886 Charleston, S. C. earthquake and its relation to the seismicity of the southeastern United States*, Long, L. T. (50)—*Intensity - distance relations for site evaluation*, Mann, O. C. (51)—*Seismicity and tectonics of the central United States*, Nuttli, O. W. and Zollweg, J. E. (54)—*The seismicity and apparent tectonics of central Washington*, Pfluke, J. H. and Pitt, A. M. (55)—*Seismicity and tectonics of northeastern North America: Results from the Lamont-Doherty network*, Sbar, M. L. *et al.* (57)—*Force pulse on a circular area as an earthquake model for near field*, Singh, S. K. (58)—*Seismic characteristics of southeast Missouri as indicated by a regional telemetered microearthquake array*, Stauder, W. *et al.* (58)—*Seismic hazard in North Carolina*, Stewart, D. M. (58)—*Recent South Carolina seismicity*, Tarr, A. C., Carver, D. L. and King, K. L. (61).

● **1.2-11 Fifth symposium on earthquake engineering**, Sarita Prakashan, Meerut, U.P., India, Nov. 1974, 2 vols., 546.

The Fifth Symposium on Earthquake Engineering was held at the Univ. of Roorkee from Nov. 9-11, 1974. The symposium was sponsored by the School of Research and Training in Earthquake Engineering, Univ. of Roorkee, the Indian Society of Earthquake Technology and the Institution of Engineers (India). Sixty-eight papers are contained in the two proceedings volumes. In addition, Volume 1 contains an author index and Volume 2 contains the general session reports and discussions concerning some of the conference papers. All of the papers are abstracted in this volume of the *AJEE*.

Volume 1

Section A—Nuclear Power Plants and Special Structures: *Geotechnical considerations for siting nuclear power plants*, Nivargikar, V. R. and Christian, J. T.—*Response of a typical reactor building to strong motion earthquake*, Nori, V. V. *et al.*—*Earthquake resistant design of electrical high voltage transmission lines*, Syrmakezis, C. A.—*Seismic analysis of hyperbolic cooling towers*, Arya, A. S. and Thakkar, S. K.—*Frequency response of towershaped structures*, Radhakrishnan, R.—*Seismic analysis of the ventilation stack for the Madras atomic power project*, Iyengar, R. N. *et al.*

Section B—Dams and Hydraulic Structures: *Static and Dynamic analysis of an arch dam*, Chandrasekaran, A.

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R. *et al.*—*Behaviour of concrete gravity dams subjected to earthquakes*, Saini, S. S. and Kulkarni, V. H.—*Design seismic coefficient and costs of gravity dams*, Chandorkar, A. V.—*Behaviour of a buttress dam*, Chandrasekaran, A. R., Petrovski, J. and Bickovski, V.—*A study on the dynamic stability of rock-fill dams during earthquakes based on vibration failure tests of models*, Okamoto, S. *et al.*—*Seismic design of earth dams*, Bhave, M. V.—*Earthquake risk as a design criterion in water resources projects*, Rao, P. V.—*Calculation of added mass of circular and rectangular piers oscillating in water*, Rao, P. V.—*Experimental verification of added mass concept as used for finding frequency of reservoir-dam systems*, Chandrasekaran, A. R. and Gupta, S.—*Earthquake resistant design of spillway bridge of Kolkewadi Dam*, Arya, A. S. and Kumar, K.

Section C—Dynamic Properties of Soils and Soil-Structure Interaction: *An experimental study of normal modes of vibration of saturated alluvium*, Stephenson, W. R.—*Behaviour of soil under oscillatory shear stresses*, Prakash, S., Nandakumaran, P. and Bansal, V. K.—*Stress condition effects on dynamic properties of soils*, Kuribayashi, E., Iwasaki, T. and Tatsuoka, F.—*Liquefaction studies of large saturated sand samples excited on a shaking table*, Gupta, Y. P.—*An application of finite element method to soil-foundation interaction analyses*, Kuribayashi, E. and Iida, Y.—*Effect of embedment and soil properties on the fundamental frequency of stiff multistorey buildings*, Chandrasekaran, A. R., Petrovski, J. and Bickovski, V.—*Evaluation of structure response supported on deep soil deposits*, Christian, J. T. and Nivargikar, V. R.—*Dynamic behaviour of a subsurface tubular structure*, Kuribayashi, E., Iwasaki, T. and Kawashima, K.—*Evaluation of relative density of cohesionless soils*, Sharma, K. K.

Section D—Applied Soil Dynamics: *Finite element analysis for the seismic stability of earth structures*, Agrawal, P. K., Gupta, D. C. and Kumar, V.—*Mechanisms involved in the failure of natural slopes and embankments due to earthquakes*, Ayyar, T. S. R.—*A new method of stability analysis of retaining walls in seismic areas*, Saran, S. and Prakash, S.—*Earth pressure coefficients for ultimate lateral resistance of laterally loaded vertical piles*, Ranjan, G. and Bhargava, S.—*Vibrations of block type machine foundations due to impact loads*, Wedpathak, A. V. *et al.*—*Design of machine foundation using the reduced natural frequency-area relationship*, Sridharan, A. and Raman, J.—*Design of foundation for gas compressor*, Gupta, M. K. *et al.*

Section E—Vibration Analysis of Structures: *An alternate approach to seismic analysis of structures*, Singh, M. P. and Chu, S. L.—*Optimum aseismic design of multistory frames*, Rao, J. V. N. and Kapoor, M. P.—*Probability of failure of structures under earthquake excitations*, Iyengar, R. N. and Jagadish, K. S.—*Seismic energy dissipation in frame structures*, Pekau, O. A.—*Matrix analysis of complex dynamic structures*, Cheng, F. Y.—*Use of transfer matrices in the seismic analysis of tall buildings*, Barria, D., Guendelman, T. and Monge, J.—*The dynamic stability of tall structures subjected to vertical ground motion*, Jagadish, K. S.—*An approximated expression for the mean square acceleration of earthquake ground motions*, Holzapfel, A., Arias, A. and Saragoni, G. R.

Section F—Behaviour of Buildings: *Interpretation of damages to the Charaima Building and their significance regarding present methods of seismic analysis and design*, Mahin, S. A. and Bertero, V. V.—*An experimental study on the behavior of steel reinforced concrete cruciform frames*, Morino, S., Nakamura, T. and Wakabayashi, M.—*Response of a reinforced concrete shear wall structure during the 1972 Managua earthquake*, Bertero, V. V., Mahin, S. A. and Hollings, J.—*Inelastic behaviour of reinforced concrete structures during earthquakes*, Chandra, B. and Prakash, R.—*The inelastic response of a 20-storey reinforced concrete frame to Koyna earthquake*, Ramesh, C. K. and Dantwala, N. M.—*A survey of the 1st February 1974 Izmir (Turkey) earthquake*, Karaesmen, E.

Section G—Instruments and Measurements: *Development of a borehole strainmeter for insitu stress measurements*, Chandra, B. and Sharma, A. P.—*Roorkee silica tube strainmeter installation at Pophali Maharashtra, India*, Kumar, V., Agrawal, P. N. and Arya, A. S.—*Measurement of small scale movements in active tectonic areas*, Agrawal, P. N., Singh, V. N. and Arya, A. S.

Section H—Behaviour of Materials: *Masonry structures in earthquakes*, Oppenheim, I. and Desai, K.—*Interlocking bricks for earthquake-resistant houses*, Keightley, W. O.—*Hysteretic behaviour of reinforced concrete beams under influence of shear and bending*, Celebi, M.—*Determination of seismic response for prestressed concrete beams*, Paz, M. and Cassaro, M. A.

Section I—Seismology: *Statistical analysis of seismic environment in New York State*, DeCapua, N. J. and Liu, S. C.—*Hazard exposure*, Chou, I. H.—*Experimental evaluation of wave attenuation in rocks*, Zadgaonkar, A. S.—*Ground particle motions in rock very close to low yield underground explosions*, Nand, K. *et al.*—*Seismic modelling for engineering and exploration seismology problems*, Singh, S. *et al.*—*Dynamics of progressive fracturing and spatial development in the source region of the Koyna earthquakes and energy density*, Gosavi, P. D. *et al.*—*Development of a seismic system for identification of shallow reflections*, Singh, S.

Section J—Seismo-Tectonics: *Earthquake activity in India during 1970–1973*, Chaudhury, H. M. and Srivastava, H. N.—*Tectogenesis and seismotectonics of the Himalaya*, Srivastava, L. S., Sinha, P. and Singh, V. N.—*Earthquake activity in Eastern Mediterranean*, Roussopou-

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los, A. A.—*Seismic zoning of Bangla Desh*, Chouhan, R. K. S. and Khan, A. A.

Volume 2

Permissible stresses and damping factors in nuclear power plants, Arya, A. S., Chandrasekaran, A. R. and Thakkar, S. K.—*Full-scale model studies of nuclear power stations for earthquake resistance*, Kirillov, A. P., Ambriashvili, Ju. K. and Kozlov, A. V.—*Seismic risk evaluation for Inguri Hydroelectric Station*, Golovin, V. A. *et al.*—*On calculation of pile foundation under seismic load*, Ilijichev, V. A. and Mongolov, Yu. V.

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2. Selected Topics in Seismology

2.1 Seismic Geology

2.1-1 Tchalenko, J. S. and Berberian, M., **Dasht-e Bayaz Fault, Iran: Earthquake and earlier related structures in bed rock,** *Geological Society of America Bulletin,* **86**, 5, May 1975, 703-709.

An 18-km-long segment of bedrock of the Dasht-e Bayaz earthquake fault was studied in detail to define the 1968 earthquake-related and earlier tectonic deformations. Ground displacements that accompanied the earthquake coincided precisely with the pre-existing east-trending fault trace. Maximum components of offset were 4 m left-lateral and 1 m south side relatively down. The bedrock displacement occurred along new tension fractures that strike on average at 50°, as well as along reactivated pre-existing structures. Earlier tectonic deformation also produced tension fractures (post-Pliocene), conjugate shears (Pliocene), and tension joints (pre-Pliocene), and all are consistent with 47° to 55° tectonic compression. The study covered three points: (1) the 40° to 45° angle measured between the major principal stress direction indicated by the earthquake fractures and the fault; (2) the apparent constancy of the stress field direction during the three early phases and the 1968 deformation; and (3) the "gap" and "anti-Riedel" structure shown by the overall fault trace, which, the authors suggest, are characteristic of situations of kinematic restraint and are associated with a nonuniformly propagating rupture.

2.1-2 Thatcher, W., **Strain accumulation and release mechanism of the 1906 San Francisco earthquake,** *Journal of Geophysical Research,* **80**, 35, Dec. 10, 1975, 4862-4872.

Re-examination of geodetic data has shown that significant crustal deformation both preceded and followed the great 1906 earthquake (M = 8.3). In the ~50 years prior to 1906, tensor shear strain rates averaged over an ~100-km-wide region spanning the San Andreas system ranged from 0.4 to 0.9 x 10^{-6} yr^{-1}, rates being higher east of the San Andreas Fault than west of it. Part of this accumulated strain was released abruptly by seismic slip on the fault in 1906, but aseismic strain release continued at a rate of ~1.2 x 10^{-6} yr^{-1} near the fault for about 30 years following the earthquake. Since that time the rate has been near 0.3 x 10^{-6} yr^{-1} both close to the fault and in a broad region surrounding it. The mechanism suggested to account for these observations is the progressive failure of most of a 450-km-long segment of the San Andreas plate boundary during an ~80-year interval. The seismic slip, averaging near 4 m, is relatively shallow, being constrained by the data to depths no greater than about 10 km. The seismic moment determined from long-period surface wave amplitudes is 4.0 x 10^{27} dyne-cm and agrees well with the geodetic estimates. Continued aseismic slip of 3-4 m below the seismic zone to depths of ~30 km explains all of the postseismic data well. The small number of pre-earthquake observations is consistent with rapid slip on the fault at greater depths. Finally, the observation of a high rate of strain accumulation prior to 1906 casts considerable doubt on the often quoted 100-year periodicity of great earthquakes on the San Andreas Fault, which appears to have originated with H. F. Reid's inferences based on the pre-1906 deformation.

2.1-3 Thatcher, W., **Strain accumulation on the northern San Andreas fault zone since 1906,** *Journal of Geophysical Research,* **80**, *35*, Dec. 10, 1975, 4873-4880.

Post-1906 geodetic surveys in the region of the great San Francisco earthquake have provided some details on the pattern and mechanism of the strain accumulation now occurring between 37° and 38°N on the San Andreas fault system. Tensor shear strain rates have averaged 0.3 x 10^{-6} yr^{-1} during 1907-1963 in a ~70-km-wide region around San Francisco Bay. Postearthquake effects on the San

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Andreas Fault persisting for ~30 years following 1906 can account for most of the early observations. However, since ~1940 and perhaps earlier, faults to the east of the San Andreas have played an important role in the strain accumulation. Since about 1950, shear straining in the San Francisco Bay area has been uniform across an 80-km-wide region immediately to the east of the San Andreas. The maximum shear strain direction is approximately parallel to the Calaveras Fault and is distinctly different from both the strike of the San Andreas Fault and the local direction of relative plate motion. At Point Reyes, ~70 km northwest of San Francisco, shear strains are concentrated near the San Andreas and Rogers Creek faults and are significantly smaller than strains observed further southeast, averaging only 0.17 x 10^{-6} yr^{-1} (1938–1961) across a 70-km-long triangulation arc extending northeast from Point Reyes. Taken together, all of these observations indicate the importance of fault slip at depth in the strain accumulation process but also suggest that the San Andreas plate boundary may become progressively more locked northwest of San Francisco.

● 2.1-4 **Fault location and evaluation: Veterans Administration Hospital, Sepulveda, California,** Woodward-Lundgren & Assoc., Oakland, July 1974, 28.

This report is a detailed study of the Northridge Hills Fault which traverses a portion of the Veterans Admin. Hospital property in Sepulveda, California. The fault is a thrust or reverse fault with a northerly dip which may range from 45° to 80°. This means that the fault plane continues downward, to the north, beneath the hospital complex at an angle between 45° and 80° from horizontal, and that the hospital complex is located north of the surface location of the fault and on the upthrown block. The upthrown block or upper plate is that portion of the earth's surface which has been elevated by thrust or reverse movement along the dipping fault plane. The hospital complex is situated very near or possibly at the edge of this upthrown block. This location could be significant in that during faulting the upper plate of a thrust fault sometimes experiences subsidiary faulting, ground cracking, and deformation above the main fault trace. The subsidiary faulting and ground cracking were very obvious along the Sylmar segment of the San Fernando fault zone in the 1971 San Fernando earthquake.

This study does not reveal any evidence of fault traces crossing the hospital complex where the structures are situated or any conclusive evidence that the Northridge Hills Fault is active. However, the scope of this study is limited to surface evaluations and does not include any subsurface exploration required for more positive evidence.

2.1-5 Thatcher, W., **Strain release mechanism of the 1906 San Francisco earthquake,** *Science,* **184,** *4143,* June 21, 1974, 1283–1285.

Re-examination of geodetic data has shown that aseismic slip occurred on or near the San Andreas Fault in the period of about 20 years after 1906. The inferred displacements are comparable to but at greater depths than the sudden slip that occurred at the time of the earthquake. The postseismic slip is constrained only between late 1906 and 1925, and data are insufficient to determine the movements, if any, below about 20 km on the fault. Two independent observations also indicate substantial anomalous crustal deformation away from the fault at least 30 years before the earthquake.

2.1-6 Bulanzhe, Yu. D. and Magnitskiy, V. A., **Contemporary movements of the earth's crust. State of the problem,** *Physics of the Solid Earth, 10,* Oct. 1974, 618–621.

A brief survey of the main results of a study of the problem is presented; attempts to explain the observed properties of vertical movements are described.

2.1-7 Gerver, M. L. *et al.*, **Problems of global computer geophysics,** *Physics of the Solid Earth, 10,* Oct. 1974, 627–634.

The results of work on global problems of computer geophysics are discussed. The work was carried out in 1960–1974 by a team consisting of workers at the Earth Physics Inst., the Inst. of Applied Mathematics and Chemical Physics of the Academy of Sciences of the U.S.S.R. and Moscow and Leningrad universities. The work covers automation of preliminary analyses of data, the solution of inverse problems, mathematical modeling, logical analysis of heterogeneous data, construction of complex models of large regions and estimations of seismic risk.

2.1-8 **Results of studies of seismicity and seismic prospecting in the Georgian S.S.R.** (Nekotorye rezultaty seismicheskikh i seismorazvedochnykh issledovanii na territorii Gruzinskoi SSR, in Russian), Metsniereba, Tbilisi, 1973, 145.

Results of investigations into the structure of the earth's crust based upon seismological data are presented. Various problems in the tectonics of the Caucasus and the statistical time distribution of earthquakes in the region are discussed.

2.1-9 Saull, V. A. and Williams, D. A., **Evidence for recent deformation in the Montreal area,** *Canadian Journal of Earth Sciences,* **11,** *12,* Dec. 1974, 1621–1624.

Pop-ups (elongated domes) in quarries at Terrebonne and St. Eustache near Montreal suggest that the region is in nearly east-west compression. Wrench faulting on pre-existing normal faults could be an important response to this stress, as it was to similar stress during the late

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Paleozoic. This concept may therefore be important in assessing earthquake hazard in the region.

2.1-10 Yamashina, K., **Strain accumulation in the Fukui area, possibly caused by the adjacent major earthquakes preceding the Fukui earthquake of 1948** (in Japanese), *Zisin, Jounal of the Seismological Society of Japan*, **28**, *4*, Dec. 1975, 415-427.

The fault parameters of Japanese earthquakes from 1926-1948 are referred to, and their contribution to strain accumulation is computed in the Fukui area. This area includes Honshu, Japan, where a large earthquake occurred in 1948 (M = 7.3, 136.2°E, 36.1°N, depth about 20 km, JMA). Taking the focal mechanism of the strike-slip Fukui earthquake into consideration, the discussion is developed with respect to the increase or decrease of the strain component, which would play an essential role in the present faulting.

Of special interest is the contribution by several major shocks, such as the Tottori (1943), the Tonankai (1944), and the Nankai (1946) earthquakes, which immediately preceded the present event and resulted in a significant increase in the strain component. Quantitatively, the present effect may cause changes of approximately 6×10^{-7} in strain, and 200 mb in stress. It is questionable whether small disturbances of this magnitude always can be a definitive trigger. In some critical cases, however, a fractional change in strain or stress may play an essential role. Further knowledge about the present effect is needed for better understanding of the focal processes.

2.1-11 Anderson, D. L., **Accelerated plate tectonics**, *Science*, **187**, *4181*, Mar. 21, 1975, 1077-1079.

The concept of a stressed elastic lithospheric plate riding on a viscous asthenosphere is used to calculate the recurrence interval of great earthquakes at convergent plate boundaries, the separation of decoupling and lithospheric earthquakes, and the migration pattern of large earthquakes along an arc. It is proposed that plate motions accelerate after great decoupling earthquakes and that most of the observed plate motions occur during short periods of time, separated by periods of relative quiescence.

2.1-12 Hill, D. P., Mowinckel, P. and Peake, L. G., **Earthquakes, active faults, and geothermal areas in the Imperial Valley, California**, *Science*, **188**, *4195*, June 27, 1975, 1306-1308.

A dense seismograph network in the Imperial Valley recorded a series of earthquake swarms along the Imperial and Brawley faults and a diffuse pattern of earthquakes along the San Jacinto Fault. Two known geothermal areas are closely associated with these earthquake swarms. This seismicity pattern demonstrates that seismic slip is occurring along both the Imperial-Brawley and San Jacinto fault systems.

● **2.1-13** Kumar, V., Agrawal, P. N. and Arya, A. S., **Roorkee silica tube strainmeter installation at Pophali Maharashtra, India**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 355-358.

A 10 m long silica tube strainmeter has been installed in the inter-adit of the Pophali Powerhouse. The system is described and the test records obtained are given. It is proposed to use future records for examining the strain buildup, if any, in the surface layer.

● **2.1-14** Agrawal, P. N., Singh, V. N. and Arya, A. S., **Measurement of small scale movements in active tectonic areas**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 359-362.

The crustal rocks in active tectonic regions suffer deformation in response to the ambient stress field. The nature of deformation (elastic or plastic) depends upon the type (compression or tension), duration (transient or long term) and magnitude of the stress field. In regions free from major discontinuities (faults or thrusts), the deformation manifests itself as elastic strain, whereas the stresses tend to be relieved more readily along faults or thrusts by slip movement. Therefore, the measurements of elastic strain in the first case and slip vector in the second are helpful in the evaluation of the present-day seismic status of these areas. A critical study of the number of independent measurements needed for getting complete data under various possible field conditions is presented.

● **2.1-15** Healy, J. H. and Peake, L. G., **Seismic velocity structure along a section of the San Andreas Fault near Bear Valley, California**, *Bulletin of the Seismological Society of America*, **65**, 5, Oct. 1975, 1177-1197.

Intensive study of an earthquake sequence along a section of the San Andreas Fault near Bear Valley, California (Feb.-Mar. 1972) reveals large velocity changes in the vicinity of the fault. These velocity changes are caused primarily by structural variations in the vicinity of the fault zone but may represent in part the effect of active tectonic processes.

● **2.1-16** Singh, S., **Development of a seismic system for identification of shallow reflections**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 421-426.

The study involves the development of a seismic reflection system which can be used to look ahead of an

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excavation face in a tunnel or a mine in order to provide early warning of hazardous or geologically changing conditions. Penetration distances into rock are, at a *minimum*, several tens of feet. Experimental data from large quarry blocks are presented.

● **2.1-17** Boatwright, J. and Boore, D. M., **A simplification in the calculation of motions near a propagating dislocation,** *Bulletin of the Seismological Society of America,* **65,** *1,* Feb. 1975, 133–138.

From Haskell's integral representations for the near-field displacements due to a propagating strike-slip and dip-slip dislocation, a solution is obtained for a dislocation "line source" by an analytic integration in the direction of the fault propagation. This reduces the numerical integration from a surface integral required for the usual evaluation of the near-field motion, to a one-dimensional integration over the fault width. Since the dislocation function modeled here is a Heaviside step function, these results may be extended to any arbitrary source time-function by convolving these displacements with the time derivative of the desired source function.

● **2.1-18** McKeown, F. A., **Relation of geological structure to seismicity at Pahute Mesa, Nevada Test Site,** *Bulletin of the Seismological Society of America,* **65,** *3,* June 1975, 747–764.

Some of the abundant and unique geological and seismological data acquired at the Nevada Test Site are integrated with the objectives of (1) resolving some of the ambiguity in explanations of the source of aftershocks of nuclear explosions, and (2) demonstrating the value of using detailed geological and seismological data to infer realistic source parameters of earthquakes.

The distribution of epicenters of aftershocks from nuclear explosions at Pahute Mesa suggests that they are related to faults or intersections of faults in the buried ring-fracture zones of calderas rather than to the conspicuous basin-and-range faults exposed at the surface. Histograms of fault length show clearly that faults in a basin-and-range regime differ significantly in length, median length, and distribution of length from faults in a caldera regime. A histogram of fault lengths derived from magnitudes of aftershocks shows both the median and distribution characteristics of caldera faults rather than of basin-and-range faults. Cumulative frequency-fault length-squared plots also show differences in the two fault regimes, and have slopes, herein called *bf* slopes, of −0.89 and −1.08 for caldera and basin-and-range faults, respectively. The *bf* slopes are similar to the average slope of a cumulative frequency-strain plot for aftershocks rather than to the *b* slopes for cumulative frequency-magnitude plots. Although the significance of *b* and *bf* slopes and differences between them are not resolved clearly, it is concluded that the fault length and strain data reflect dimensions of seismic sources rather than energy of seismic events.

The principal conclusion of the investigation is that the most obvious geology of a seismically active area may not provide the proper basis for inferring seismic-source parameters.

● **2.1-19** Piwinskii, A. J., **Experimental studies of granitoid rocks near the San Andreas fault zone in the Coast and Transverse ranges and Mojave Desert, California,** *Tectonophysics,* **25,** *3/4,* Feb. 1975, 217–231.

In western California, Mesozoic calc-alkaline plutons, consisting of approximately 39% quartz monzonite, 36% granodiorite, 23% quartz diorite and 1% gabbro-diorite, occur in terrains displaced by the San Andreas fault zone from Bodega Head south to the intersection of the Big Pine and Garlock faults. Because these granitoids can potentially be utilized as possible markers of fault movement, the results of recent geochemical, petrochemical, and geochronological studies are considered. These investigations include the water-saturated phase equilibrium relationships of granitoids from the Coast Ranges, Transverse Ranges, Mojave Desert, and Central Sierra Nevada batholith, California, determined to 10 kbar water pressure. The data are compatible with approximately 500 km offset along the San Andreas fault zone since Cretaceous time.

● **2.1-20** Abe, K., **Static and dynamic fault parameters of the Saitama earthquake of July 1, 1968,** *Tectonophysics,* **27,** *3,* July 1975, 223–238.

The source mechanism of the Saitama earthquake (36.07°N,139.40°E,M_S = 5.4) of July 1, 1968, is studied on the basis of P-wave first motion, aftershock, long-period surface-wave data and low-magnification long-period seismograms recorded in the near field. A precise location of the aftershocks is made using P and S-P time data obtained by a microearthquake observatory network. The synthetic near-field seismograms based on the Haskell model are directly compared with the observed near-field seismograms for wave form and amplitude to determine the dynamic fault parameters. The results obtained are as follows: source geometry, reverse dip slip with considerable right-lateral strike-slip component; dip direction, N6°E; dip angle 30°; fault dimension, 10 × 6 km^2; rupture velocity, 3.4 km/sec in the direction S30°E; average dislocation, 92 cm; average dislocation velocity, 92 cm/sec; seismic moment, 1.9 × 10^{25} dyne-cm; stress drop, 100 bar. The effective stress is about the same as the stress drop. For major earthquakes in the Japanese islands, the dislocation velocity is found to be proportional to the stress drop. This result has an importance in engineering seismology because the stress drop scales the seismic motion in the vicinity of an earthquake fault.

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● **2.1-21** Tandon, A. N. and Srivastava, H. N., **Focal mechanisms of some recent Himalayan earthquakes and regional plate tectonics,** *Bulletin of the Seismological Society of America,* **65,** *4,* Aug. 1975, 963–969.

Focal mechanism solutions of 12 recent earthquakes along the northern boundary of the Indian-Eurasian plates, from Hindukush to Burma, have been determined assuming the double-couple hypothesis. It has been found that the majority of earthquakes are of thrust type with the pressure directions acting at right angles to the faults/mountains, but, for a few of the earthquakes, the orientations of the pressure directions are almost along the strike of the faults. Such observations could be partly explained in terms of the concept of "flake tectonics" as proposed for continent-continent collisions. A number of earthquakes in the eastern Himalayas and Burma show normal dip-slip or predominantly strike-slip movements. These anomalies call for further refinements of the plate theory in this zone of complicated deformation.

2.1-22 Savage, J. C., **A possible bias in the California State geodimeter data,** *Journal of Geophysical Research,* **80,** *29,* Oct. 10, 1975, 4078–4088.

Although the California geodimeter network has been surveyed repeatedly over a period of almost 15 years, three different procedures have been employed successively in the periods 1959–1964, 1964–1969, and 1969–1974. Direct comparison of the last two procedures suggests a discrepancy of about 13 mm + 0.8 ppm in line length measurement, the post-1969 measurements being longer. An analysis of the temperature measurements used to compute the refractivity correction suggests a discrepancy between the line length measurements of 1959-1964 and 1964–1969 amounting to perhaps 0.8 ppm, the 1964-1969 measurements being longer. It would appear that the discrepancy between the 1959-1964 and 1969–1974 procedures might lead to an apparent shortening of geodimeter lines by 13 mm + 1.6 ppm, which for an average length line (23 km) amounts to almost 50 mm. The bias is statistical in nature and cannot be removed from individual measurements. The observed discrepancies are plausible consequences of the usual nocturnal ground level temperature inversion, but definite proof of a causal relation is lacking. The bias is capable of accounting for several anomalies in the interpretation of the geodimeter data (e.g., the apparent dilatancy near Parkfield reported by Cherry and Savage).

2.1-23 Savage, J. C., **Further analysis of the geodetic strain measurements on the Denali Fault in Alaska,** *Journal of Geophysical Research,* **80,** *26,* Sept. 10, 1975, 3786–3790.

Unbiased analysis of repeated surveys of a section of the primary triangulation arc along the Richardson Highway provides no evidence of lateral deformation on the Denali Fault, a major dextral transcurrent fault in the Alaska range. The measured shear strain accumulated in the 29-year period between surveys is consistent with an extension normal to the fault of about 23 ± 4 μstrain and apparently represents strain release at the time of the 1964 Alaska earthquake. A dislocation model for the Alaska earthquake is used to demonstrate that strain relaxation of this magnitude at the Denali Fault is consistent with other geodetic strain observations. The absence of significant right lateral deformation on the Denali Fault in the 29-year period between surveys suggests that the rate of strain accumulation there must be quite small (engineering shear strain rate is probably 0.1 μstrain/year or less).

● **2.1-24** Schneider, G., **Seismotectonic parameters as a basis for seismic risk evaluation,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 158, 5. (For a full bibliographic citation see Abstract No. 1.2–8.)

Seismotectonic parameters, such as focal surface, focal dislocation, stress drop and fracture velocity, are parameters determining the shape of a seismic time function or spectra when measured close to the focal volume. The relation between macroseismic efficiency and such parameters is studied. Statistical models for description of seismotectonic processes are discussed. Examples are taken from active areas in Western Europe.

2.1-25 Utsu, T., **Correlation between shallow earthquakes in Kwanto region and intermediate earthquakes in Hida region, central Japan** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **28,** *3,* Oct. 1975, 303–311.

A correlation has been found between intermediate earthquakes in Hida (the region around the city of Takayama) and shallower earthquakes in central Kwanto (the region around the city of Tokyo). Among 61 earthquakes of $M \geq 5.5$ in central Kwanto during the 51 years from 1924 through 1974, 37 earthquakes occurred in the one-year periods centered by the times of 16 earthquakes of $M \geq 5.0$ in Hida. The probability that 37 or more earthquakes in central Kwanto occurred during those periods (total length = 14.46 years) is 1.5×10^{-7}, if the Kwanto earthquakes were distributed randomly in time. It seems impossible that the smallness of this probability is wholly attributable to effects other than the true correlation, such as the selection of data, the clustering of earthquakes, etc. The correlation suggests a mechanical connection between the two seismic regions, which belong to the same segment of the Pacific plate underthrusting at the northeastern Japan arc.

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2.2 Wave Propagation

● 2.2-1 Bakun, W. H. and Bufe, C. G., **Shear-wave attenuation along the San Andreas fault zone in central California,** *Bulletin of the Seismological Society of America,* **65,** *2,* Apr. 1975, 439–459.

SH ground-displacement spectra (1 to 12 Hz) for 16 local earthquakes ($\Delta \leq 18$ km, $1.1 \leq M \leq 4.6$) recorded at a common site situated atop the active trace of the San Andreas Fault are used to estimate attenuation characteristics for propagation paths along the fault trace. $t^* = 0.10$–0.13 (corresponding to an equivalent total path $Q\beta = 75$–100) is appropriate for events with focal depths of ~10 km.

Propagation-path effects, and not processes at the earthquake source, control corner frequencies for small ($M < 3$) earthquakes for these highly attenuating paths. The results obtained here suggest that, as a rule of thumb, if the true equivalent total path Q is as low as $4 \cdot f_c \cdot t$, where f_c is the estimated corner frequency and t the travel time, the corner frequency estimate is determined by propagation-path effects, not by processes at the earthquake source. In these cases, reliable estimates of source parameters can be obtained only if the appropriate propagation-path corrections are known.

Using Brune's model of shear-wave spectra, source dimensions $L = 2r$ of less than 250 m and stress drops greater than about 1/10 bar are estimated for the smaller events ($1.1 \leq M \leq 2.2$), using the equivalent total path $Q\beta$ obtained here. The seismic moments obtained in this study, together with data for larger central California events ($2.4 \leq M_L \leq 5.1$) obtained by Johnson and McEvilly (1974), imply a linear log seismic moment–magnitude relation for $1 < M_L < 5$

$$\log_{10}(M_0) = (16.2 \pm 0.1) + (1.52 \pm 0.05)M_L.$$

2.2-2 Ipatova, O. S. and Rykunov, L. N., **Modelling of the influence of topographic irregularities upon seismograms,** *Physics of the Solid Earth, 11,* Nov. 1974, 741–746.

This article describes the basic results of an experimental investigation of secondary surface waves which developed in two dimensional models during the conversion of longitudinal waves into surface waves at the free boundary of a statistical random relief. The results are compared with theoretical calculations. Important aspects of the modeling method are considered for the case of a statistically irregular topography of the free boundary. The space and time dependent correlations of the secondary surface wave are considered. Recommendations are given.

● 2.2-3 Zadgaonkar, A. S., **Experimental evaluation of wave attenuation in rocks,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 401–404.

An analog method for studying the attenuation of elastic waves in rocks within a frequency range of 50 to 10^8 Hz has been evaluated at different frequencies. The attenuation characteristics of rock specimens from around Raipur have been determined. A significant spread in attenuation factor has been found, which may possibly be accounted for by the change in propagation speed due to different dissipation mechanisms.

● 2.2-4 Kurita, T., **Attenuation of shear waves along the San Andreas Fault in central California,** *Bulletin of the Seismological Society of America,* **65,** *1,* Feb. 1975, 277–292.

Ground motions at distances of 20 to 30 km from two moderate earthquakes, which occurred along the San Andreas fault zone in central California on Feb. 24, 1972 ($M = 5.0$) and on Sept. 4, 1972 ($M = 4.6$), were well recorded at two stations on quite different crustal structures astride the fault. The similarity of the focal mechanisms and the observed spectra at each station, for both earthquakes, makes it possible to apply the spectral ratio method for evaluating Q for direct shear waves propagating along and adjacent to the fault zone. The resultant linear relations between the average values of Q of *SH* waves for the wave paths from both earthquakes to each station, together with a few reasonable assumptions, suggest the following properties of the variation of Q in the upper crust: In the fracture zone of Tertiary and Cretaceous sedimentary rocks along the fault to the northeast of the Gabilan Range, the average Q in the upper 6 km is as low as 20. Although less certain, under the northeastern part of the Gabilan Range composed of Mesozoic granites southwest of the fault, the average Q in the upper 6 km is about 100 or more and the intrinsic Q begins to decrease at a depth of several kilometers. This depth corresponds to the bottom of the well-defined zone of aftershock occurrence following moderate earthquakes.

● 2.2-5 Martincek, G., **Propagation of shear stress waves in layered media,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 19, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The propagation of horizontally polarized shear stress waves in layered elastic and viscoelastic media which leads to frequency equations with complex roots is solved. Frequency equations are introduced for elastic one- and two-layered systems on elastic halfspaces and for a viscoelastic layer on a viscoelastic halfspace. Also introduced are the numerical methods used to solve the equations and graphs of the dispersion curves of phase velocities and those of dissipation.

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● **2.2-6** Gürpinar, A., **Power spectrum representation of earthquake motions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 20, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The problem of random wave propagation in layered elastic media is examined. By use of the transfer function method, a relationship between the power spectra of the motion at any layer within the medium and at the stress free boundary was established earlier. In this paper, the results obtained from this earlier work are applied to geodynamic problems resulting from random earthquake motion. The application is concentrated on two types of local soil conditions: hard and soft, and the discussion of the influence of parameters is focused on these two categories. The use of white-noise simulation for hard ground is justified theoretically, and useful relationships are obtained for soft soil, between-layer thicknesses and modal periods given by the power spectra.

2.2-7 Lander, A. V., **On interpretation of the results of spectral-time analysis** (O metodike interpretatsii rezultatov spektralno-vremennogo analiza, in Russian), *Vychislitelnaya seismologiya, 7,* 1974, 279-315.

The choice of an optimal system of filters for spectral-time analysis is studied. A systematic error formula is obtained. Problems in the interpretation of results are considered. The techniques of constructing dispersion curves of surface waves are discussed.

2.3 Source Mechanisms

2.3-1 Street, R., Herrmann, R. B. and Nuttli, O. W., **Earthquake mechanics in the central United States,** *Science,* 184, *4143,* June 21, 1974, 1285-1287.

Focal mechanism solutions of earthquakes in the central United States suggest that local stress fields are important in determining the type and orientation of faulting. The implied stress system is considerably more complicated than that which would be produced by east-west trending compressive stresses, as previously suggested for this region.

● **2.3-2** Gosavi, P. D. *et al.*, **Dynamics of progressive fracturing and spatial development in the source region of the Koyna earthquakes and energy density,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 415-420.

Continuous monitoring of the Koyna earthquakes (1964-69) with a closely spaced net of observatories equipped with highly sensitive and precision instruments afforded a unique opportunity for assessing the detailed characteristics of the source region of these earthquakes and its three-dimensional development (active volume) with respect to space and time. The source region underwent very little change in active volume and energy density during the foreshock period. However, the region underwent an abrupt change in active volume and energy density with the main earthquake on Dec. 10, 1967. During the subsequent period of aftershocks, the source region remained moderately active, gradually extending in size though with a much-reduced rate.

Monthly active volume (V_i), associated energy (E_i) and energy density (E_i/V_i) of the source show significant variations with time with the largest values occurring during the main Koyna earthquake of Dec. 10, 1967. The following statistical relation, as suggested by Kisslinger (1968) for the Matsushiro earthquakes, is also found to broadly hold good for the energy density of the Koyna earthquake source: $\log E_i/V_i = AM_i + B$. The coefficient A is significant, about 1.6; as such the monthly energy density depends on monthly equivalent magnitude (M_i), contrary to earthquake energy density predicted from Bath-Duda and Gutenberg-Richter equations. The final energy density for Koyna earthquake source levels off at 500 ergs/cm^3. Similar results were found for the Matsushiro earthquake source in Japan.

Close instrumental studies of the development of active volume and associated energy in the source region of the Koyna earthquakes throw significant light on the dynamics of progressive fracturing of the rock mass subjected to overall geotectonic stress field and ultimately on the processes leading to gradual stability in the source region.

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

2.4-1 Chinnery, M. A. and North, R. G., **The frequency of very large earthquakes,** *Science,* **190,** *4220,* Dec. 19, 1975, 1197-1198.

Observational data relating surface wave magnitude M_s to seismic moment M_0 are used to convert a well-known frequency-M_s plot into a frequency-M_0 relationship, which turns out to be remarkably linear. There is no evidence of an upper bound to M_0, on the basis of presently available evidence. The possibility exists that extremely large earthquakes ($M_0 = 10^{31}$ dyne-cm or greater) may occur from time to time.

● **2.4-2** Hawkins, N. M. and Crosson, R. S., **Causes, characteristics and effects of Puget Sound earthquakes,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 104-112.

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In this paper a review is made of the existing knowledge of earthquake records for the Puget Sound region, and the records are collated with current information on the tectonics, geology, soil conditions and building practices for the region. This information indicates that differences between seismic effects for the Puget Sound region and California are likely to be repeated in future earthquakes and that these differences should be taken into account for future planning, development, and construction in the region.

2.4-3 Borisov, B. A. and Reysner, G. I., **On a new seismo-tectonic catalog of the Caucasus,** *Physics of the Solid Earth,* 9, Sept. 1974, 552-556.

A new version is presented of the seismo-tectonic catalog of the Caucasus, which was compiled from the results of seismological and geological studies. It characterizes the peculiarities of the tectonic development of the seismic regions in the Alpine, the most recent and the contemporary stages. The geological-geophysical description relates the equiareal, circular parts of the territory, including the epicentral zones of strong earthquakes (magnitude $M > 5$).

● 2.4-4 Chou, I. H. and Fischer, J. A., **Earthquake hazard and confidence,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 34-42.

Two problems associated with the determination of seismic risk at a site are discussed: what kind of mathematical process should be used to model earthquake occurrence and how suitable is the data base. The first discussion involves an evaluation of the advantages of the Weibull time-dependent distribution process for modelling earthquake occurrence over the Poisson process, which assumes that the hazard rate is constant and independent of time. The second problem involves a discussion of the advantage of using confidence limits as an appropriate measure of the suitability of the data base and the reliability of the answer.

● 2.4-5 Alsinawi, S. and Ghalib, H. A. A., **Historical seismicity of Iraq,** *Bulletin of the Seismological Society of America,* **65,** 2, Apr. 1975, 541-547.

Iraq has a rather long, well-documented history of seismic activity, where 79 events of major and/or minor effects on the community are documented for the period 1260 B.C. through 1900 A.D. Fourteen of these events are listed and described for the first time from an Arabic manuscript.

The historical seismicity follows a well-defined pattern and fits with the boundaries of the major tectonic units of Iraq, as well as with the recent seismicity of the country.

● 2.4-6 Ferguson, J. F. and Stewart, D. M., **Summary of North Carolina seismicity in the 18th and 19th centuries,** *Earthquake Notes,* **46,** *1-2,* Jan.-June 1975, 27-36.

A list of 59 earthquake events felt in North Carolina between 1732 and 1900 has been compiled. It is the most complete such list yet catalogued. Thirty-eight of these events probably had their epicenters within the state or within a few miles of the state line. Much of the activity cannot easily be related to known geologic structures although some of the epicenters fall near the Blue Ridge front and the Brevard zone, near the border faults of the Dan River and Deep River Triassic Basins, and in the Cape Fear Arch region. Magnitudes of the North Carolina events were all probably less than 4.5 on the Richter scale. The maximum intensities experienced were due to the New Madrid, Missouri, earthquakes of 1811-12 and the Charleston, South Carolina, earthquake of 1886. There is a correlation between the growing population of North Carolina from 1732 and the number of reported events, but the state probably became saturated with respect to seismic detection around 1855. Hence, the increase in seismic activity after 1870 is probably of genuine geologic origin. Among the most interesting events is the 1874 swarm near Rumbling Bald Mountain in McDowell County when more than 75 earthquakes occurred in two months. Field inspection of the site shows huge relatively recent-looking splits in the mountains there that could have been due to this swarm. The historical record of North Carolina is probably not long enough to be a very valid basis for making earthquake risk projections into the future. It may be that the greatest threat to North Carolina is large earthquakes outside its borders such as those in the Mississippi Valley and South Carolina. On the other hand, there is nothing now known that can rule out the possibility that the greatest threat to North Carolina is within its own boundaries. This latter possibility becomes a very real and serious concern when one studies the land elevation changes currently in progress in eastern North Carolina.

● 2.4-7 Stewart, D. M., Ferguson, J. F. and Bollinger, G. A., **Cumulative intensity mapping: A method of earthquake history analysis,** *Bulletin of the Association of Engineering Geologists,* **XII,** *3,* 1975, 165-175.

In using historic records for the estimation of earthquake probability, two questions need answering: (1) What levels of damaging intensities have been experienced? and (2) How often? Cumulative intensity mapping is a method of condensing earthquake history into a map that answers those two questions for every point in a region. The method was derived to meet the needs of engineers, building code legislators, city planners and architects. The method combines the data from conventional Modified Mercalli isoseismal maps for every earthquake experienced in the region into a single map for each intensity level. Contours of cumulative intensity maps enable one to read

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directly the historical earthquake frequency for any desired intensity level for all areas on the map. It is also a method of displaying historical data simply enough to be easily understood by both laymen and scientists. The technique provides a basis for comparing earthquake histories of regions with different seismic regimes. It can be used to graphically illustrate the local importance of distant events. It can also be used as a check to see if the data sample is statistically valid in terms of the uniformity of historical coverage and/or length of time of observation.

2.4-8 Antonenko, E. M. *et al.*, **Investigations of hazards of destructive earthquakes in Alma-Ata** (Izuchenie opasnosti razrushitelnykh zemletryasenii dlya territorii g. Alma-Aty, in Russian), *Informatsionnyi sbornik nauchno-issledovatelnykh rabot instituta geologicheskikh nauk AN Kazakhskoi SSR*, 1974, 113–119.

A macroseismic evaluation of the Vernen and Kebin earthquakes near Alma-Ata is given. As a result of analysis of earthquakes in the destructive and perceptible category, a macroseismic map of the city is constructed. A method for investigating high-frequency microtremors to differentiate areas with various degrees of seismic risk is presented. Conditions for the most effective use of microtremor recordings to evaluate seismic risk are described. In order to eliminate the effects of random factors not amenable to our analysis on the microtremor parameters, repeated control measurements performed at the same locations were found necessary.

● 2.4-9 Bune, V. I. *et al.*, **Applications of the nonlinear transformation method for isolating zones with differing maximum earthquake magnitudes in the Crimea-Caucasian region** (Primenenie metoda nelineinykh preobrazovanii dlya vydeleniya zon s razlichnymi maksimalnymi magnitudami zemletryzsenii v Krymsko-Kavkazskom regione, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 124–136.

A method developed by the authors' collective for investigating the relationship between geological phenomena and maximum earthquake magnitudes is presented. The method uses prediction techniques based on one-dimensional nonlinear transformations. As a practical application of the method, the authors constructed a map of the entire Caucasian region showing expected M_{max} values for each rectangle with dimensions 10 ft x 15 ft. In order to verify the authors' results, a map showing expected M_{max} values for the Crimea region was also constructed using the same methods. Good agreement with recorded seismicity of the region was found.

2.4-10 Whitham, K., **The estimation of seismic risk in Canada**, *Geoscience Canada*, **2**, *3*, Aug. 1975, 133–140.

The progress and problems in the estimation of seismic risk in Canada are assessed, and the uncertainties of the approaches tried in the past are analyzed. Some of the conclusions are that seismic risk estimates in Canada are severely hampered by the lack of an adequate tectonic framework, that the historical data on earthquakes may not be adequate for the expression of seismic risk in the present national codes, and that the design earthquake approach is more realistic and more valid than approaches used in the past.

● 2.4-11 Cornell, C. A. and Merz, H. A., **Seismic risk analysis of Boston**, *Journal of the Structural Division, ASCE*, **101**, *ST10*, Proc. Paper 11617, Oct. 1975, 2027–2043.

The application of analytical seismic risk analysis to the city of Boston is presented. Emphasis is on selection of parameter values and sensitivity of results to variation in parameter values. The results are presented in terms of a plot of the annual probability of equalling or exceeding site intensity x versus x. Motion intensity is described in several alternate forms: modified Mercalli intensity, peak ground acceleration, response spectra, etc.

● 2.4-12 Douglas, B. M. and Ryall, A., **Return periods for rock acceleration in western Nevada**, *Bulletin of the Seismological Society of America*, **65**, *6*, Dec. 1975, 1599–1611.

A method is described for determining expected acceleration return periods, based on calculations involving magnitude, fault length and distance to the causative fault. The method permits earthquake magnitude and duration of strong motion to be associated with these return periods. In addition, because attenuation equations are in terms of distance to the causative fault, instead of focal distance, sites can be considered which are in the immediate vicinity of potential faults. Results of calculations indicate that for an average site in the western Nevada region maximum-amplitude, maximum-duration ground motion has a recurrence time of the order of thousands of years. This result, based on a relatively brief sample of instrumental data, is entirely consistent with geological field data representing time periods two to three orders of magnitude longer. Smaller ground motions have correspondingly smaller return periods, down to about a decade for accelerations greater than 0.1 g, when caused by all earthquakes with magnitude 5 or greater. The authors' results indicate that evaluation of seismic risk in terms of a single peak ground-motion parameter may lead to risk estimates which are several times too high.

● 2.4-13 Kaila, K. L. and Rao, N. M., **Seismotectonic maps of the European area**, *Bulletin of the Seismological Society of America*, **65**, *6*, Dec. 1975, 1721–1732.

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Seismicity maps based on A value, b value, and return period for earthquakes with magnitude 6 and above have been prepared for the European area using the Kaila and Narain method. For the preparation of these maps, a modified relation $A = 6.36b-1.00$ has been used instead of the earlier relation where A and b are constants in the cumulative regression curve represented by $\log N = A-bM$. The A-value seismicity map also shows regional tectonics superimposed on it, thus yielding the seismotectonic map of Europe. These seismicity maps reveal that the European area consists of seven main high seismic activity zones named the Balkan high, the Aegean high, the Apennine-Sicilian high, the Alps high, the Carpathian high, the Saharan-Pyrenees high and the Iceland-Arctic high, which are described in detail along with their relationship to regional tectonics. Using earthquake regression curves for various regions of Europe, the authors determine b values by the new method. These values, which are shown on a b-value seismicity map, are compared with those determined by other investigators and are found to be in very good agreement with them.

● 2.4-14 DeCapua, N. J. and Liu, S. C., **Statistical analysis of seismic environment in New York State,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 389-396.

The seismic risk map that appears in the Uniform Building Code divides New York State into areas of three different risk levels, i.e., Zones 1, 2 and 3. However, some ambiguities and confusion with regard to its interpretation and applications still exist. This is largely attributed to the facts that the boundary lines between different risk zones are vaguely defined, the accuracy in the assessment of relative risk levels for different risk zones is unclear, and most significantly, the earthquake occurrence frequency of the area is not taken into consideration.

In order to more reliably identify the earthquake environment of New York State, a comprehensive statistical analysis of seismicity data observed since 1638 is undertaken in this paper. The entire study region is divided into 48 finite subregions. To minimize over- or underestimates of statistical quantities based on finite records, overlapped data in adjacent regions with different weighting factors are used. The earthquake sequence is treated as a Poisson process and each of the 48 subregions is considered as an area source.

The basic conclusion resulting from the analysis is that no part of New York State can be justified as a Zone 3 high-risk area as specified in the current Uniform Building Code. The earthquake environment of the state can perhaps be best described as low to moderate, with infrequent high-intensity events. A reasonably well-designed structure would not suffer any substantial earthquake-induced damage during a normal service life. Therefore, unless a special situation arises, no additional earthquake protection should be required for structures built in New York State.

● 2.4-15 Chou, I. H., **Hazard exposure,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 397-400.

It is realistic to consider that hurricanes, storms, floods and earthquakes are random natural phenomena. Traditionally, the probabilistic description of these phenomena for the designer is in terms of return period. For example, in a Poisson model, the probability of having at least one event in the corresponding return period is 63 per cent. This somehow misleads designers. The purpose of this paper is to introduce a meaningful description for these phenomena. The risk level is defined as the probability of at least one occurrence during the considered life expectancy. The return period is defined as the time interval during which the expected number of occurrences is one. From the probabilistic model of random phenomenon, a dimensionless ratio of design return period to life expectancy can be obtained as a function of the risk level.

Two models for forecasting the occurrence of an earthquake are studied. One (Poisson) assumes the rate of occurrence is constant and independent of time; the other (Weibull) assumes the rate as being a function of time. Naturally, the ratio of design return period to life expectancy will increase as the risk level decreases. After the risk level is chosen, the required design return period can be obtained from the product of the ratio of design return period to life expectancy and life expectancy. The design return period can then be used to find the corresponding magnitude, intensity or acceleration level. Because risk is always inevitable in seismic design, the decision must be made to minimize the expected loss. The risk level is clearly defined and can be readily considered in making design decisions.

● 2.4-16 Chaudhury, H. M. and Srivastava, H. N., **Earthquake activity in India during 1970-1973,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 427-434.

The seismic activity in and near India during 1970-73 is discussed in the light of newly determined focal mechanism solutions, geological faults and plate tectonics. Of significance are the recent increase in earthquakes in Jammu and Kashmir and their aftershock characteristics and focal mechanisms. The two recent instrumentally determined earthquakes in the Bay of Bengal are significant both from the standpoint of seismicity and from the standpoint of the theory of plate tectonics. They could not be associated with any known geological fault. Their mechanism solutions, however, define an NNE striking fault dipping to the east at angles ranging from 55° to 70°, where movement is predominantly left-lateral strike-slip.

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The swarm-type activity near Mandya and Sindgi and the recent Koyna earthquake bring to light the need for a detailed geological investigation along peninsular India. A critical review of the recent focal mechanism solutions indicates that their correlation with regional plate tectonics is only partially valid for the continent-continent type of collision boundaries of the Indian and Eurasian plates.

● 2.4-17 Srivastava, L. S., Sinha, P. and Singh, V. N., **Tectogenesis and seismotectonics of the Himalaya,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 435–442.

On the basis of past earthquake data, the Himalayan region can be divided into three seismic provinces. An attempt has been made to study the influence of peninsular lineaments in the evolution of the seismotectonic framework of the Himalaya. Tectogenesis of the Himalaya appears to be related with cymatogenic warping of the crust and uplift due to undulation of the Moho, and this process is probably still operative.

It has been suggested that an understanding of the seismotectonics and tectogenesis of the Himalaya is of great importance in assessing the seismic risk of the region and in assessing the damage potential of earthquakes to engineering structures in the region.

● 2.4-18 Roussopoulos, A. A., **Earthquake activity in eastern Mediterranean,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 443–450.

Among the different regions of the world which experience severe earthquakes, the eastern Mediterranean region is of special interest because of the numerous earthquakes that occur there and because of its complex geological structure. Three large earthquakes that occurred in Turkey are described: the Mar. 23, 1969, Demirci, the Mar. 28, 1969, Alasehir, and the Mar. 28, 1970, Gediz earthquakes. In addition, the aftershocks of each earthquake also are described.

The geological and tectonic structure of the region of the North Anatolian Fault is studied. Aftershock magnitude-frequency relations are plotted. The relative movements of the Aegean and the Turkish plates can influence the seismicity of the region, which extends along the boundaries of these two plates. The north-south boundary between these plates passes slightly through the Gediz region. An attempt is made to show the dependence of the three major earthquakes on each other and the relation of the earthquakes to the movements of the tectonic plates.

● 2.4-19 Toppozada, T. R., **Earthquake magnitude as a function of intensity data in California and western Nevada,** *Bulletin of the Seismological Society of America,* **65,** *5,* Oct. 1975, 1223–1238.

Using published intensity data for California and western Nevada earthquakes, from 1950 through 1971, magnitude was related to maximum reported intensity, area of perceptibility, and the areas enclosed by various isoseismal lines. Six relations were developed. Previously unpublished isoseismal maps, for earthquakes in the 1940's, are presented and used to test these relations. The tests show that magnitudes estimated from the maximum reported intensity may be underestimated by up to 1.3 magnitude units, but that magnitudes estimated from various isoseismal areas are generally within 0.5 units of the published values.

● 2.4-20 Rikitake, T., **Statistics of ultimate strain of the earth's crust and probability of earthquake occurrence,** *Tectonophysics,* **26,** *1/2,* Mar. 1975, 1–21.

Statistics of ultimate strain are improved by adding new data to the previous data. The critical value for horizontal strain seems somewhat larger than that for vertical strain, although parameters of a Weibull distribution, which is customarily used for quality-control research and which fits in very well with the present statistics, are calculated for the whole set of data, making no distinction between the two subsets because of their scantiness.

On the basis of the parameters thus determined and strain rates obtained from geodetic data, probabilities of earthquake occurrence in a few regions in Japan and the U.S. are estimated. The probability of having an earthquake in an area southwest of Tokyo, where the 1923 earthquake (magnitude 7.9) occurred, is at this time 20%, a value almost the same as that obtained in the previous papers. The probability will reach somewhere between 50 and 90% by 2000 and 2050, respectively. In the North Izu District, where an earthquake of magnitude 7.0 occurred in 1930, a shearing crustal motion is occurring. Because of the extent of this motion, there is a 40% probability that an earthquake will recur during the next 40 years. By the end of this century, it will become as high as 85%.

Similar estimates of such cumulative probabilities are made for the San Francisco and Fort Tejon regions, where great earthquakes occurred respectively in 1906 and 1857, yielding values of 30 and 80% at present. These probabilities are tentative because of possible errors in evaluating geodetic measurements and because of the uncertainty of the ultimate crustal strain assigned to the San Andreas Fault.

● 2.4-21 Hagiwara, Y., **A stochastic model of earthquake occurrence and the accompanying horizontal land deformation,** *Tectonophysics,* **26,** *1/2,* Mar. 1975, 91–101.

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A large-scale earthquake is believed to be associated with a release of strain energy accumulated in the crust, probably by the motion of upper-mantle lithosphere. Such an earthquake mechanism is well simulated by a belt-conveyor model proposed by Utsu. The probability of earthquake occurrence can be estimated on the assumption that the motion of a slider on the belt-conveyor is mathematically formulated as a Markov process.

In the probabilistic expressions, the results of Mogi's rock fracture experiments are applied to the hazard-rate function of earthquake occurrence. The hazard-rate function has two coefficients, A and B, to be determined by the experiments. It is concluded that, when B is small, a number of small-scale earthquakes occur in the early time after the accumulation of crustal strain energy starts, but that the accumulated strain energy changes catastrophically into a single large-scale earthquake, when B is large.

● 2.4-22 Bath, M., **Seismicity of the Tanzania region,** *Tectonophysics,* 27, 4, Aug. 1975, 353-379.

The seismicity of the East African Rift system within the region bounded by latitudes 2°N and 12°S and longitudes 28°E and 40°E has been studied as far as all available instrumentally based material permits. An earthquake catalog is presented, and the data contained therein are used for tectonophysical investigations, including frequency-magnitude relations and time and space distribution of the seismicity within the region. In addition, earthquake engineering aspects are discussed.

● 2.4-23 Maasha, N., **The seismicity and tectonics of Uganda,** *Tectonophysics,* 27, 4, Aug. 1975, 381-393.

The seismicity of Uganda has been studied using new data and all other available, previously determined locations of earthquakes ($m_b \geq 4.0$) up to Dec. 1973. A magnitude-frequency graph suggests that since 1963 there has been nearly complete coverage of all events with body magnitudes $m_b \geq 4.2$ in Uganda. The distribution of the earthquakes affirms that the Lake Amin-Lake Mobutu region experienced the greatest number of earthquakes, while the area around the Ruwenzori Mountain is probably the most seismically active area in Uganda—if not in East Africa. The occurrence of earthquakes and the presence of faults of Cenozoic Age in the Ruwenzori fold belt indicate that this area is a tectonically active zone (zone of weakness) probably connecting the eastern and western rifts across the Lake Victoria basin.

2.4-24 Riznichenko, Y. U. *et al.,* **The seismic shakeability of California,** *Physics of the Solid Earth,* 11, 5, Dec. 1975, 285-291.

Using data from American observations recorded in the period 1934-1961, the authors have calculated the long-term mean indices of seismicity for California, including the seismic activity and the maximum possible earthquake magnitudes. The mean frequency or risk of recurrence of seismic tremors of various intensities is determined. This has been done by methods developed and widely used in the U.S.S.R. In addition, a number of basic general questions of seismic zoning methodology are discussed on the basis of seismic activity maps.

● 2.4-25 Gülkan, P. and Yücemen, M. S., **A seismic risk study of Izmir,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 160, 11. (For a full bibliographic citation see Abstract No. 1.2-8.)

Izmir is the third largest city in Turkey, and the largest city within the most active seismic zone. In this paper, plots of annual risk versus the intensity of "firm" ground motion in Izmir are drawn by making use of epicentral locations, magnitudes and intensities of earthquakes of the last 71 years. The influence of the various parameters affecting the annual risk is systematically studied, and a Bayesian estimate is presented. The design response spectrum with a given return period is drawn.

● 2.4-26 Shah, H. C. *et al.,* **A study of seismic risk for Nicaragua,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 154, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper summarizes the results of a seismic risk study conducted at Stanford. In general, the paper presents the future probabilistic seismic loading determination of Nicaragua and how that loading can be used to determine future damage potential and "insurance risk." Suggestions regarding seismic zoning of the country also are presented.

● 2.4-27 Moazami-Goudarzi, K., **Quantification of seismicity in Iran,** *Bulletin of the International Institute of Seismology and Earthquake Engineering,* 13, 1975, 1-7.

Historical earthquakes of the past 13 centuries and recent instrumental data concerning the seismicity of the Iranian Plateau are used to calculate the quantification factors of the seismicity of the different regions in Iran. According to this study these factors vary between 1×10^{-3} and 8×10^{-3} in historical earthquakes, while with the instrumental data they vary between 1×10^{-2} and 10×10^{-2} earthquakes per year for $\Delta \leq 100$ km, $M \geq 6$ and $h \leq 50$ km. Such discrepancies are discussed in this paper. This study shows the general aspect of the seismicity of different parts of the Iranian Plateau.

● 2.4-28 Eguchi, R. T., **An earthquake risk model that incorporates local near surface site conditions,** *UCLA-ENG-7547,* School of Engineering and Applied Science, Univ. of California, Los Angeles, June 1975, 117.

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An earthquake risk model that incorporates local near surface site conditions was developed and applied to the Los Angeles area. In the model, the occurrences of earthquakes in time, magnitude and space are represented by probability distributions which have been developed by others. However, the particular joint distribution of the three was developed as a part of this study.

The estimation of risk is expressed in terms of two ground motion indices, modified Mercalli intensity and maximum particle velocity. Special emphasis is given to establishing the effect of local site geology on the estimation of risk. Local site factors for intensity have been adopted from the work of others, while site factors for maximum particle velocity were developed as a result of this study. The site factors for maximum particle velocity required the establishment of a near surface model.

Data from the 1971 San Fernando earthquake are utilized to develop attenuation relationships for maximum particle velocity and modified Mercalli intensity. The effects of including and excluding aftershocks on the probabilities were observed.

Five examples are presented, three in terms of modified Mercalli intensity and two in terms of maximum particle velocity. Comparisons are made among the examples. A general discussion of the limitations and merits of the methods used is presented.

2.5 Studies of Specific Earthquakes

● 2.5-1 Crosson, R. S. and Frank, D., **The Mt. Rainier earthquake of July 18, 1973, and its tectonic significance,** *Bulletin of the Seismological Society of America,* **65,** *2,* Apr. 1975, 393-401.

On July 18, 1973, a magnitude 3.9 earthquake was strongly felt at Longmire and surrounding areas near Mt. Rainier, Washington. Network analysis permitted an accurate hypocenter to be located at 46°49.29′N and 121°49.86′W at a depth of 10.9 km, about 7 km southwest of the summit of Mt. Rainier. No prolonged aftershock sequence was generated, although two small aftershocks were recorded and located. Aerial photographs of the epicentral region reveal several northwest-trending lineaments which may be related to active faults in the region, although no surface ground breakage was discovered. The focal mechanism obtained for the main shock is well constrained and consistent with right-lateral strike-slip motion along a northwest-trending fracture, in general agreement with northwest-trending surface lineaments. The nature of the relationship of the earthquake occurrence to Mt. Rainier is uncertain. The principal compressive axis direction is in agreement with that found in the central Puget Sound basin. However, the shallow depths, the strike-slip mode of faulting, and the past evidence of earthquakes near Mt. Rainier suggest a direct relationship between faulting, earthquake generation, and the volcano location.

● 2.5-2 Sbar, M. L. *et al.*, **The Delaware-New Jersey earthquake of February 28, 1973,** *Bulletin of the Seismological Society of America,* **65,** *1,* Feb. 1975, 85-92.

The largest earthquake to affect northern Delaware in 100 years occurred at 08:21 GMT on Feb. 28, 1973. The event was perceptible over 15,000 km^2 in New Jersey, Delaware, Pennsylvania, and Maryland with a maximum Modified Mercalli intensity of V-VI near the Fall Zone between Wilmington and Claymont, Delaware. The isoseismals are elongate in a northeast-southwest direction. The main shock had a magnitude of 3.8 and was located at 39°43.1′N, 75°26.4′W with a depth of 14.1 km as calculated by NOAA. The five aftershocks located in this study were centered within a few kilometers of the region of greatest intensity at about 39°47′N and 75°25′W with depths ranging from 5 to 8.4 km. The fault plane solution determined from the main shock and aftershocks indicates dip-slip motion on a nearly vertical plane striking N28°E. The southeast side is down in agreement with geological observations of subsidence of the Coastal Plain and uplift of the Piedmont. The strike of this fault is similar to that of the border faults of a graben in the basement rocks about 30 km southwest along the strike from the epicenter suggesting that the seismic activity may be associated with such faults.

● 2.5-3 Singh, D. D., Rastogi, B. K. and Gupta, H. K., **Surface-wave radiation pattern and source parameters of Koyna earthquake of December 10, 1967,** *Bulletin of the Seismological Society of America,* **65,** *3,* June 1975, 711-731.

The fundamental-mode Rayleigh waves for the Koyna earthquake of Dec. 10, 1967, recorded on long-period vertical component seismograms of 30 WWSSN stations have been Fourier analyzed. The radiation patterns have been plotted at six wave periods. Comparison of these data with the theoretical radiation patterns computed for various fault parameters favored the strike of the fault in N10°E direction, dip 78°W, slip 175°, and the depth of focus to be 10 km. Strike-slip faulting on a near-vertical fault plane has been inferred. The S-wave polarization angles, which have been obtained for 13 stations, also favor the above solution. Surface-wave magnitude has been determined to be 6.3 and the fault surface area to be 252 km^2. Using the Rayleigh-wave spectral amplitude for 50-sec period, the seismic moment, M_o, is determined to be 0.82 x 10^{26} dyne-cm. The values of average dislocation, seismic energy, apparent stress, and apparent strain are calculated to be 108 cm, 2.25 x 10^{21} ergs, 15.4 bars and

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5.3×10^{-5}, respectively. For a rupture velocity of 1.5 km/sec, the values of fault length and stress drop are found to be about 23 km and 19.8 bars, and for a rupture velocity of 3.0 km/sec these values are about 40 km and 6.2 bars, respectively.

● 2.5-4 Ellsworth, W. L., **Bear Valley, California, earthquake sequence of February-March 1972,** *Bulletin of the Seismological Society of America,* **65,** 2, Apr. 1975, 483-506.

The earthquake sequence of late February and March 1972 involved movement along the San Andreas Fault and within the crustal wedge enclosed by the branching San Andreas and San Benito faults near Bear Valley, San Benito County, California. Activity was mainly confined to three distinct zones of strike-slip faulting: the short north-trending aftershock zone of the M 3.5 earthquake of Feb. 22, 1972, the aftershock zone of the M 5.0 Bear Valley earthquake of Feb. 24, 1972, located along the San Andreas Fault, and the west-trending aftershock zone of the M 4.6 earthquake of Feb. 27, 1972. The north-trending and west-trending zones lie between the two major splays of the branching fault system. Focal mechanism solutions from events in these zones are consistent with the transfer of horizontal, dextral displacement from the San Andreas Fault to the San Benito, Paicines and Calaveras faults within the Bear Valley region. During the 18 months preceding the February 1972 sequence, the hypocentral regions of both the M 5.0 and M 4.6 shocks were characterized by concentrations of small earthquakes. Aftershock source areas of these two events progressively expanded during the course of the aftershock sequence. Estimates of the mainshock rupture surface for these events based on the distribution of aftershocks range over a factor of 4 owing to the irregular distribution of aftershocks and the rapid growth of the aftershock zone.

● 2.5-5 Benson, A. F., Stanford, C. F. and Fogle, G. H., **Intensity survey of Charleston, South Carolina earthquake November 22, 1974,** *Earthquake Notes,* **46,** *1-2,* Jan.-June 1975, 15-26.

An intensity survey conducted by Law Engineering Testing Co. indicates a maximum epicentral intensity VI Modified Mercalli for the Nov. 22, 1974, earthquake near Charleston, South Carolina. Isoseismals, based on returned newspaper questionnaires and field investigation, show an elongated pattern in a northwest-southeast direction near the epicentral area. At a distance of approximately 60 miles from the epicentral area, the intensities decrease to III MM. An area elongated in a northeast-southwest trend along the fall line (approximately 100 miles from the epicenter) experienced intensity IV MM.

Field investigation of the damage reports verified slight damage characteristic of intensity VI MM in three small areas in the Charleston vicinity. These areas may be reflective of localized soil conditions. Isolated reports of cracked plaster and bricks were received from the Augusta, Georgia, and Columbia, South Carolina, areas. Aftershocks of much less severity than the initial shock have been reported from the epicentral area.

● 2.5-6 Tandon, A. N., **Some typical earthquakes of north and west Uttar Pradesh,** *Bulletin of the Indian Society of Earthquake Technology,* **12,** 2, Paper No. 153, June 1975, 74-88.

Three earthquakes that occurred in north and west Uttar Pradesh in recent times, viz., the Bulandshahar earthquake of Oct. 10, 1956, the Kapkote earthquake of Dec. 28, 1958, and the Moradabad earthquake of Aug. 15, 1966, have been redetermined and fault plane solutions have been calculated. Finally a correlation between the tectonic setup of the region and earthquake occurrence is given.

2.5-7 Wetmiller, R. J., **The Quebec-Maine border earthquake, 15 June 1973,** *Canadian Journal of Earth Sciences,* **12,** *11,* Nov. 1975, 1917-1928.

On June 15, 1973, a shallow-focus earthquake with magnitude m_b 4.8 occurred in southern Quebec, in an area that has a record of only a few minor earthquakes during the previous 200 years. This event was felt throughout southern Quebec, eastern Ontario and the New England states, to a distance of 300 km from the epicenter. A small amount of minor damage to plaster and chimneys occurred in the immediate epicentral area, indicating a maximum intensity of VI. The focal mechanism solution suggests that the earthquake was the result of primarily strike-slip movement along a plane trending northeast or a plane trending northwest. Arguments are presented that this event is part of the seismicity associated with the northern Appalachian Mountains.

● 2.5-8 Hart, E. W., **Ground rupture associated with faulting,** *California Geology,* **28,** *12,* Dec. 1975, 274-276.

On Aug. 1, 1975, a magnitude 5.7 earthquake occurred in the Oroville-Palermo area of California. Subsequently, numerous associated earthquakes have occurred in that area. Aside from damage and other secondary effects caused by the shaking, surface ground fractures were created in the area east of Palermo. Most of these fractures apparently were caused by shaking effects and are secondary. However, one set of northwest-trending fractures four miles east of Palermo is clearly related to primary faulting. This fracture zone delineates a fault (referred to as the Cleveland Hill Fault) not identified prior to the Aug. 1975 earthquakes. This report, although based on limited observations, shows that the zone of fractures west of Cleveland

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Hill is directly related to displacement along a pre-existing fault.

2.5-9 Okada, Y., **Strain- and tilt-steps associated with the two earthquakes, which occurred in the east off Hachijojima, Japan, on February 29 and December 4, 1972** (in Japanese), *Zisin, Journal of the Seismological Society of Japan*, 28, *4*, Dec. 1975, 387-413.

The source mechanisms of two earthquakes that occurred east off Hachijojima, Japan, are studied. The Feb. 29, 1972, earthquake had a magnitude of 7.0 and the Dec. 4, 1972, earthquake had a magnitude of 7.2. Data on the strain and tilt steps observed in Japan were collected and compared with theoretical step data based on fault-origin models.

Generally, the strain data are systematic and, to some extent, consistent with the theoretical data. Surprisingly, the patterns of the spatial distribution of steps characterizing the two events are quite different from one another. This may be naturally attributed to the difference in their source mechanisms as derived from the radiation pattern of the P-waves. Direct plots of the step amplitude versus epicentral distance show a large scattering of data, which is difficult to explain by a simple formula.

The theoretical steps at the observational sites were calculated by referring to Ichikawa's fault plane solutions and by using explicit expressions for surface strains and tilts caused by an arbitrarily oriented double-couple source buried in a semi-infinite elastic medium. Comparison of theory with observation suggests that the moments are 2.3×10^{27} cgs for the Feb. 29 earthquake and 1.2×10^{27} cgs for the Dec. 4 earthquake. However, these values are erroneous due to considerable scattering of the data. The tilt-step data appear to be more erroneous; at times the observations show the amplitude to be ten or more times larger than the theoretical predictions. This conclusion is difficult to explain by a simple model. Various causes may be suspected. One of the likely causes is that at present continuous tilt observations are calculated primarily with small-sized pendulum-type tiltmeters, which may be disturbed more easily by local conditions than such large-sized instruments as water-tube tiltmeters. When selecting data in the future, careful attention should be paid to the instrumental conditions at each station.

● 2.5-10 Ando, M., **Source mechanisms and tectonic significance of historical earthquakes along the Nankai trough, Japan**, *Tectonophysics*, 27, *2*, June 1975, 119-140.

Two recent and three historical earthquakes which occurred along the Nankai trough, marking the northern plate boundary between the Philippine Sea and the Asian Plate, are studied on the basis of crustal deformation and tsunami wave data. These earthquakes are the 1946 Nankaido, the 1944 Tonankai, the 1854 Ansei I, II and the 1707 Hoei earthquakes. They are all interpreted as low-angle thrust faults at the plate boundary, with the oceanic side underthrusting northwestward against southwestern Japan. The fault parameters of the historical earthquakes are assumed to be common to those of the two recent earthquakes, except for the magnitude of dislocation.

The entire fault region, which extends for 530 km from western Shikoku Island in the west to the Tokai District in the east, is divided into four fault planes, which are denoted planes A, B, C and D from west to east, respectively. Then, the five earthquakes may be attributed to the planes A, B, C and D in the following manner: the Nankaido earthquake, A + B; the Tonankai earthquake, C; the Ansei II earthquake, A + B; the Ansei I earthquake, C + D; and the Hoei earthquake, A + B + C + D.

The latest cycle of earthquake migration seems incomplete as proved by the recent inactivity in D. Consequently, the next future major earthquake is expected to occur there—off the Tokai District. Eight ancient earthquakes from A.D. 684 to 1605 also are discussed. Taking the results of the foregoing studies into consideration, their sequence is well interpreted by the four migration cycles. Topographical data, tilt of coastal terraces and location of hinge lines prove that the thrusting has continued all along the extension of the Nankai trough for at least 300,000 years.

● 2.5-11 Denham, D., Everingham, I. B. and Gregson, P. J., **East Canning Basin earthquake, March 1970**, *Journal of the Geological Society of Australia*, 21, *3*, Sept. 1974, 353-358.

On Mar. 24, 1970, an earthquake of magnitude ML 6.7 took place in the eastern Canning Basin. The earthquake was unusual because it occurred in a region where no previous earthquake had been reported and where there was no evidence of recent tectonic activity. First motion results indicate a thrusting-type focal mechanism with the pressure axis approximately northeast-southwest and dipping about 24° to the southwest. The main shock was followed over the next two years by many earthquakes in a zone covering 140 km by 20 km. The longitudinal axis of this zone is approximately parallel to the north-northwest striking nodal plane determined from the first motion results and to the trend of intrabasin faulting.

It is suggested that continental crust may be sensitive to small changes in stress pattern and consequently seismic activity may be interrelated over large distances.

● 2.5-12 Everingham, I. B., **Faulting associated with the major north Solomon Sea earthquakes of 14 and 26 July 1971**, *Journal of the Geological Society of Australia*, 22, *1*, Mar. 1975, 61-69.

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Major tsunamigenic earthquakes occurred on July 14 and July 26, 1971, about 100 km apart in the Solomon Sea. The second earthquake is not considered to be an aftershock of the first: aftershock patterns and fault-plane solutions indicate that both were the result of movements along two separate parts of a major arcuate fault surface. The first earthquake caused movement along the part of the fault that extends south-southeast, the second in the part that extends west-southwest, from southernmost New Ireland.

The two aftershock zones overlapped to the south-southeast of New Ireland near the epicenter of the July 26 earthquake and where its fault rupture commenced. The rupturing was probably due to the effects of the July 14 earthquake series.

Aftershock and first-motion data indicate that the area between Bougainville Island, southern New Ireland, and southeastern New Britain is being underthrust from the south. The fault surface appears to be concave downwards with depth and dip increasing towards the islands to the northwest, north, and northeast.

During both earthquakes, intensities of at least MM8 were experienced; their isoseismals form ellipses whose long axes coincide with the trend of the relevant aftershock zone (i.e., south-southeast for the first earthquake, west-southwest for the second). Maximum intensities apparently occurred above the aftershock region. Evidence suggests a surface-wave magnitude of 8.0 for both earthquakes.

2.6 Seismic Water Waves

2.6-1 Savatyugin, L. M., **On the possibility of tsunamis in the Southern Ocean** (O vozmozhnosti vozniknoveniya tsunami v Yuzhnom okeane, in Russian), *Informatsionnyi byulleten sovetskoi antarkticheskoi expeditsii, 89,* 1974, 72–73.

On the basis of theoretical considerations and a study of the *Catalog of Earthquakes in Antarctica,* it is concluded that the Antarctic seismic belt is sufficiently active to produce tsunamis capable of reaching the shores of Antarctica.

2.6-2 Gvelesiani, T. L., **Wave formation in water reservoirs due to seismo-tectonic displacement of banks** (Volnoobrazovanie v vodokhranilishche v rezultate seismotektonicheskogo smeshcheniya ego bortov, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94,* 1974, 45–48.

Formulas for calculating the magnitude of surface waves at a dam due to various types of seismotectonic displacements of the whole of the reservoir (dip about a horizontal axis) or of one of the banks only are presented. The formulas were obtained by solving the two-dimensional problem of the oscillations of an ideal incompressible fluid in a rectangular reservoir, when its "flexible" walls and bottom were subjected to simultaneous nonstationary seismic excitation. Calculations were performed on a computer to evaluate maximal variations in water level for a few important parameter values.

2.6-3 Adams, W. M., **Conditional expected tsunami inundation for Hawaii,** *Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE,* **101,** *WW4,* Proc. Paper 11702, Nov. 1975, 319–329.

Values were reported for a priori estimates of expected tsunami inundation, conditioned by values for epicenter location and tsunami magnitude. Those values of conditional expected tsunami inundation (CETI) were restricted to coastal locations having historical observations of tsunamis. Here a method is developed and applied for interpolating between these existing CETI to obtain predictions at coastal locations not possessing historical tsunami data. The method uses the existing CETI for calibrating (by best-fitting) the functional shape provided by the output from Bernard's time-stepping linear two-dimensional difference equations over a mesh having spatial increments of about 5 km and time steps of 15 sec (prototype time). Coastal position is measured along the coast from a reference point. Graphs for the interpolated CETI are given for the five major Hawaiian islands, assuming a tsunami magnitude of 4 arriving from the north.

● 2.6-4 Silgado Ferro, E., **History of large tsunamis on the west coast of South America** (Historia de los grandes tsunamis producidos en la costa occidental de la America del Sur, in Spanish), Centro Regional de Seismología para América del Sur, Lima, Peru, 1974, 22.

The publication consists of a catalog of the major tsunamis which occurred along the west coast of South America from 1515 to 1922.

2.6-5 Hatori, T., **Tsunami activity in eastern Hokkaido after the off Nemuro Peninsula earthquake in 1973** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* **28,** *4,* Dec. 1975, 461–471.

The source areas of the 1973 Nemuro-oki tsunami and the second tsunami accompanying the largest aftershock on June 24, 1973, are reanalyzed because of the addition of Kuril Islands mareographic data. The result is the same as shown in the preliminary report: The source length of the 1973 Nemuro-oki tsunami is 130 km long parallel to Nemuro Peninsula and the area is 7.2×10^3 km^2. The source length of the second tsunami is 100 km, which is longer than the aftershock area reported by NOAA, and the western half of the source area seems to overlap with the source area of the first tsunami.

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The third tsunami of Sept. 27, 1974, was observed to have a small amplitude at Hanasaki. The estimated source area of this tsunami is within the source area of the 1973 tsunami. The fourth tsunami of June 10, 1975, was generated by an earthquake with a magnitude of approximately 7 (JMA), but the tsunami magnitude was relatively large. According to the author's method based on the attenuation of tsunami height with distance, the tsunami magnitude (Imamura-Iida scale) is $m = 1.5$. This magnitude is the same grade as that of the 1973 Nemuro-oki tsunami. The estimated source area falls inside the source area of the 1969 Shikotan tsunami. The source length is about 100 km long and its area is 6.3×10^3 km^2. The sea bottom of this area may be uplifted, judging from the initial motion of the tsunami observed at Hokkaido and Sanriku.

The source areas of the tsunamis generated after the 1973 Nemuro-oki tsunami moved to the north-eastern direction along the continental slope. Within the source area of the 1969 Shikotan tsunami, many tsunami sources are located. On the contrary, there is a remarkable gap of the tsunami source area between the 1952 Tokachi-oki and the 1973 Nemuro-oki tsunamis. The source area of the 1973 tsunami occupies only the eastern half of the 1894 tsunami source. The area to the southwest of the 1973 tsunami may be considered a region of relatively high tsunami risk.

2.6-6 Gvelesiani, T. L., **On seismic seiches in reservoirs due to residual shear deformations along walls during earthquakes** (K issledovaniyu seismicheskikh seish v vodokhranilishche, voznikayushchikh v rezultate ostatochnykh deformatsii sdviga vdol ego bortov pri zemletryasenii, in Russian), *Soobshcheniya Akademii Nauk Gruzinskoi SSR*, **76**, *1*, 1974, 141–144.

In connection with studies of the earthquake resistance of dams, the three-dimensional problem of surface water oscillations in a prism-shaped water reservoir due to various types of horizontal seismic displacements of its walls is considered.

2.6-7 Davidson, D. D. and McCartney, B. L., **Water waves generated by landslides in reservoirs**, *Journal of the Hydraulics Division, ASCE*, **101**, *HY12*, Proc. Paper 11791, Dec. 1975, 1489–1501.

A hydraulic model investigation has been conducted to ascertain the magnitude of wave height and runup to be expected from potential landslides in Lake Koocanusa at Libby Dam, Montana. Although this investigation is of a particular site, it furnishes valuable information and insight into general problems of waves resulting from landslides that might be pertinent to other areas. The model study results show the wave heights and runup to be expected at various pool elevations as well as the effect and corrective measures proposed to reduce wave heights to an acceptable level. This paper presents the Libby prototype problem, model concepts, some experimental data, and conclusions pertinent to the prediction of landslide-generated water waves.

2.7 Artificially Generated Ground Motions or Seismic Events

2.7-1 Kurtz, S. R., **A back-of-the-envelope approach to predicting ground motion phenomena**, *Journal of Geophysical Research*, **80**, *32*, Nov. 10, 1975, 4449–4460.

An analytic model (Bote model) is presented as a means to describe the pressures at and arrival time of the spherically diverging stress wave resulting from an underground explosion. The model is based on a linear combination of the forms used to describe the two extremes in the stress wave lifetime: a strong shock at early times and a simple elastic wave at late times. The Bote model traces the propagation of the spherically diverging stress wave through the hydrodynamic, plastic, crush-up, and elastic pressure regimes and predicts the pressures at and arrival times of the shock front. While able to account for the effects of porosity and water content of the surrounding medium, the Bote model requires knowledge of only two points on the pressure-volume (*PV*) curve of the medium: the pressure P_E below which the medium is assumed to behave elastically and the pressure P_C at which all air-filled voids in the medium have been crushed out. Simple expressions are given for determining P_C and P_E as a function of water content and gas fill porosity. Other necessary Bote model inputs include explosive yield (*Y*) and medium type as well as geologic characteristics, including grain density (ρ_g), in situ density (ρ_0), water content (*W*), and sound speed (*C*). Compared with both calculated and measured ground motion data, Bote results show good agreement for times ranging from tens of microseconds to tens of milliseconds, for distances out to a scaled range of 107 m/kt$^{1/3}$, and for pressures of the order of 10^5 Pa.

● 2.7-2 Donovan, N. C. and Degenkolb, H. J., **Field measurement of relative ground displacement**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 10–16.

An experimental technique which was hastily developed and deployed to measure relative displacements during the RIO BLANCO event of May 17, 1973, is described. The work was performed for the El Paso Natural Gas Co. in anticipation of the Project Wagon Wheel in an area of Wyoming which had many concrete-lined irrigation channels.

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Two basic structural implications were found with regard to the measurements taken. The first implication is the lengthening and shortening, or accordion effect, on any long structure such as a pipeline, canal or roadway that is rigidly coupled to the ground. The second implication involves buildings of even nominal horizontal dimensions where the stresses in the floor slab and foundation ties can be of some importance. Although all of the analyses performed are not discussed in this paper, the complete conclusions and observations of the study are presented.

● 2.7-3 Springer, D. L. and Kinnaman, R. L., **Seismic-source summary for U.S. underground nuclear explosions, 1971-1973,** *Bulletin of the Seismological Society of America,* 65, 2, Apr. 1975, 343-349.

A summary of information is presented for all announced U.S. underground nuclear explosions detonated during 1971-1973. The data include detonation times, locations, and depths of burial, as well as information about shot media and surface collapse (subsidence) phenomena. This summary is an addendum to a previous publication which covered the period 1961-1970, and includes some additions and corrections to that work.

● 2.7-4 Singh, S., Agrawal, P. N. and Arya, A. S., **Microearthquake studies at Ramganga Project, Kalagarh, U.P., India,** *Bulletin of the Indian Society of Earthquake Technology,* 12, 2, Paper No. 154, June 1975, 89-100.

The Ramganga Reservoir near Kalagarh was partially filled for the first time during the 1974 summer monsoon. A study of the records from the Kalagarh Observatory from Apr. to Sept. 1974 and microearthquake recordings from July 15 to Sept. 19, 1974, has been made to examine the interrelationship of the reservoir filling and seismic activity. The results of the study are reported in this paper. The rise in reservoir water level did not bear any relation to the number of earthquakes occurring in the region.

2.7-5 Ladynin, A. V. and Tychkov, S. A., **Stresses in the earth's crust due to loads from surface topography and water reservoir (On the problem of induced seismicity in areas near major hydroelectric plants)** (Napryazhennoe sostoyanie zemnoi kory pod nagruzhoi relefa i vodokhranilishcha (K probleme vozbuzhdennoi seismichnosti v raionakh krupnykh gidrotechnicheskikh sooruzhenii, in Russian), *Metodologicheskie voprosy issledovanii sovremennykh dvizhenii zemnoi kory,* Novosibirsk, 1975, 252-266.

The hypothesis of induced seismicity, assumed to be a response of the earth's crust to changes in stress due to the weight of a reservoir, is analyzed as a two-dimensional problem of stresses in an elastic halfspace, subjected to loadings due to topographic features and the weight of the water. Numerical results are obtained characterizing stresses in the earth's crust around the Sayan Hydroelectric Power Plant and Lake Baikal. A qualitative discussion of the role of stress concentration along faults is given. An increase in ground shaking due to a reduction of focal depths is possible in the region of the Sayan Power Plant without a significant increase in focal energy.

2.7-6 Sadovskii, M. A. and Kostyuchenko, V. N., **On seismic effects of underground explosions** (O seismicheskom deistvii podzemnykh vzryvov, in Russian), *Doklady AN SSSR, 5,* 1974, 1097-1100.

Experimental data on the effects of strong underground explosions are analyzed. The number n of damaged buildings is shown to obey the log-normal distribution law and is dependent on the maximum ground motion velocity V. In the case of small explosions where the number of damaged buildings is low, the function $n(V)$ may be used to calculate the probability of various kinds of damage as well as critical ground motion velocities.

● 2.7-7 Nand, K. *et al.*, **Ground particle motions in rock very close to low yield underground explosions,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 405-408.

A large number of low-yield underground explosions (charges up to 10 kg) were made in basaltic-type rock, and ground particle accelerations, ground particle velocities and strains in rock were measured for assessing the limiting value of the above quantities during such explosions. The limiting value of ground particle acceleration observed very close to the explosion center was of the order of 50 to 100 g, in basalt. Maximum ground particle velocity and strain in basalt up to 50 cm/sec and 3000 microstrain, respectively, also were measured close to underground explosions. Such limiting ground particle motions are broadly independent of the amount of charge and are dependent only on the rock type, that is the characteristic fracture particle velocity of the medium.

● 2.7-8 Athavale, R. N., **Induced seepage along a coastal parallel system of faults as a possible cause of the Koyna earthquakes,** *Bulletin of the Seismological Society of America,* 65, *1,* Feb. 1975, 183-191.

The level of seismicity in the area around Koynanagar (17°23′N:73°45′E), Maharashtra State, Western India, has increased considerably since the commissioning of a hydroelectric project on the Koyna River in the year 1962. Analysis of available geological, geochemical, geothermal, refraction seismic, observational seismic, gravitational and paleomagnetic data for the region suggests the existence of a zone of faults, located immediately to the west of the watershed (Sahyadri ridges) and running roughly parallel to the western coast of India, approximately between latitude 17°N to 19°30′N. Geomorphological evidence for recent

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reactivation of this fault system of Miocene Age is presented.

The increase in the seismicity of the region is considered to be due to release of strain accumulated in the zone of faults. It is proposed that induced seepage in the N-S trending faults, of a fraction of the enormous quantities of water discharged in the E-W running Vaitaraní-Vashisthi rivers, at the Pophli Powerhouse, has actuated and sustained the process of release of seismic energy. Assuming that induced seepage of water is the immediate cause of the earthquakes, a method for mitigation of the seismicity level in the Koynanagar Region is suggested.

2.7-9 Martin, J. C., **The effect of fluid pressure on effective stresses and induced faulting**, *Journal of Geophysical Research*, **80**, *26*, Sept. 10, 1975, 3783–3785.

The effects of variations in fluid pressure in large, thin, horizontal aquifers and reservoirs are analyzed by assuming a condition of no horizontal strain. The results indicate that the difference in induced effective horizontal and vertical stresses, coupled with the initial stresses, determines the stability to induced faulting. Conditions characterized by thrust faulting are found to be the least stable, and those characterized by normal faulting to be the most stable. The stability to induced faulting is shown to decrease with increasing values of the intermediate effective principal stress in regions characterized by normal and wrench faulting. However, this effect is not present in regions characterized by thrust faulting.

2.7-10 Belinskii, I. V. *et al.*, **On rock fracture patterns in group underground explosions** (O nekotorykh osobennostyakh razrusheniya gornykh porod pri gruppovykh podzemnykh vzryvakh, in Russian), *Doklady Akademii Nauk Ukrainskoi SSR, Seriya A*, *4*, 1974.

An increase of the rock fracture zone in group underground explosions is explained on the basis of wave superposition. Full-scale experimental procedures are developed (diamond core drilling, core sampling), and the processing and analysis of data are discussed. Crack porosity increase due to group explosions is calculated. Good agreement between calculated and experimentally measured increases in the fracture zone is found.

2.8 Earthquake Prediction

● 2.8-1 Gupta, I. N., **Premonitory seismic-wave phenomena before earthquakes near Fairview Peak, Nevada**, *Bulletin of the Seismological Society of America*, **65**, *2*, Apr. 1975, 425–437.

Anomalous variations in three different seismic processes have been observed before an earthquake of magnitude 4 on May 14, 1971, in the Fairview Peak region of central Nevada. The data used are the three-component seismograms from Tonopah (TNP) and Battle Mountain (BMN) as well as the vertical-component seismograms from several other seismographic stations. The observed precursory phenomena are (1) reorientation of the compressive stress axis: evidence for this is based on clear reversals of first motion of *Pg* at certain stations together with reversal of wave form of the *SV* component of *Sg* at BMN; (2) vertical migration of hypocenters: the *PmP* phase is often distinctly observed in central Nevada and the observed temporal variations in *t(PmP)–t(Pg)* at TNP indicate generally upward migration of foci before the main event; (3) changes in the extent of S-wave splitting: a large precursory increase is observed along the tensile stress direction and a small premonitory decrease along the compression direction. Similar but unidentical results have been obtained before another earthquake of magnitude 4 whereas all events of magnitude 3.5 or larger have been preceded by anomalous S-wave splitting along the tension direction. The various observed pre-earthquake processes appear to be interrelated and may be explained in terms of recent laboratory and theoretical results when applied to the tectonics of central Nevada. It seems highly desirable to attempt simultaneous observations of anomalous changes in more than one seismic process.

2.8-2 Griggs, D. T. *et al.*, **Earthquake prediction: Modeling the anomalous V_P/V_S source region**, *Science*, **187**, *4176*, Feb. 14, 1975, 537–540.

Soviet observations of anomalously low values of the ratio of the compressional wave velocity to the shear wave velocity (V_P/V_S) in a restricted volume around the locus of a future earthquake are duplicated by models based on the dilatancy hypothesis. In nature the cracks that cause the dilation may be oriented, leading to anisotropic seismic wave propagation in the anomalous region. The models show that vertical cracks are most effective in producing the observed effects, but that a slightly higher density of randomly oriented cracks will yield similar effects. The premonitory observations at Blue Mountain Lake, New York, are also duplicated by the models. These models demonstrate that V_P/V_S measured at the surface is not that of the anomalous zone, but is related to it by a transfer function, involving the shape and velocity gradient of the zone boundary.

2.8-3 Hasegawa, H. S., **Seismic ground motion and residual deformation near a vertical fault**, *Canadian Journal of Earth Sciences*, **12**, *4*, Apr. 1975, 523–538.

Ground motion and residual ground deformation at strategic points in the epicentral region of an idealized, vertical shear fault that may correspond to an intermediate magnitude (6–6½) earthquake are displayed and analyzed. For analytical purposes, Haskell's expressions for the elastic displacements near a propagating fault are sepa-

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rated into two parts, the near-field and the far-field terms. The distance from the fault at which the far-field terms are sufficient to describe the total field varies, depending upon the orientation of particle motion relative to that of the dislocation (slip) vector. For the component of particle motion parallel to the dislocation vector, this distance is comparatively greater than that for the perpendicular component. The Earth Physics Branch strain gauge, which has a threshold sensitivity of about 5×10^{-10}, has the capability of detecting residual strain at least as far as 100 km from the hypothetical fault. The Earth Physics Branch tiltmeter, which can detect a step change in tilt in the range 5×10^{-9} to 5×10^{-10} radians, can detect residual tilt at least as far as 50 km from the causative fault.

The high-frequency slope of the theoretical Fourier amplitude spectrum of ground acceleration (*FS*) is not appreciably steepened by the addition of the near-field to the far-field terms. The implication of this observation is that the steep slope observed at high frequencies on *FS* curves of predominantly California earthquakes cannot be attributed, even in part, to the source mechanism assumed but must be attributed entirely to travel path effects such as attenuation and scattering.

2.8-4 Wyss, M., **Precursors to the Garm earthquake of March 1969,** *Journal of Geophysical Research,* **80,** *20,* July 10, 1975, 2926-2930.

The average P residual increased by 0.4 sec 1.2 yr before the M_L = 5.7 Garm earthquake of Mar. 22, 1969. This is interpreted to indicate a decrease in the P velocity by approximately 10-20% in the local crust. The P wave precursor time is slightly shorter than that indicated by a preferred alignment of the compression axes and by a decrease in local seismicity (Nersesov *et al.*, 1973). Barsukov (1972) reported a decrease of apparent resistivity 0.6 yr before the same event. All precursor observations were obtained within a radius of 25 km of the epicenter and outside the 6 by 10 km aftershock zone. The precursor volume must have exceeded the source dimensions by a factor of 5.

2.8-5 Myachkin, V. I. *et al.*, **Experimental and theoretical investigations of processes that are possible forerunners of earthquakes,** *Physics of the Solid Earth, 10,* Oct. 1974, 676-679.

A review is given of the main results of experimental and theoretical investigations carried out in the Inst. of Physics of the Earth of the Academy of Sciences of the U.S.S.R. on the processes that are possible forerunners of earthquakes. These results substantially complete the various field investigations of the same processes.

2.8-6 McGarr, A., **Earthquake prediction: Absence of a precursive change in seismic velocities before a tremor of magnitude 3 3/4,** *Science,* **185,** *4156,* Sept. 20, 1974, 1047-1049.

P-wave velocities in the region near the source of a tremor of magnitude 3 3/4 were constant to within 2 percent for 41 days before the event; no evidence of a precursive change in velocity was found. Observations of S-wave velocities and the ratio of P-wave to S-wave velocities also showed no precursive changes. In recent studies, premonitory changes in body-wave velocities of about 10 percent and having a duration of 2 to 3 weeks have been reported for crustal earthquakes of this size.

2.8-7 Mazzella, A. and Morrison, H. F., **Electrical resistivity variations associated with earthquakes on the San Andreas Fault,** *Science,* **185,** *4154,* Sept. 6, 1974, 855-857.

A 24 percent precursory change in apparent electrical resistivity was observed before a magnitude 3.9 earthquake of strike-slip nature on the San Andreas Fault in central California. The experimental configuration and numerical calculations suggest that the change is associated with a volume at depth rather than some near-surface phenomenon. The character and duration of the precursory period agree well with those of other earthquake studies and support a dilatant earthquake mechanism model.

2.8-8 Robinson, R., Wesson, R. L. and Ellsworth, W. L., **Variation of P-wave velocity before the Bear Valley, California, earthquake of 24 February 1972,** *Science,* **184,** *4143,* June 21, 1974, 1281-1283.

Residuals for P-wave travel times at a seismographic station near Bear Valley, California, for small, precisely located local earthquakes at distances of 20-70 km show a sharp increase of nearly 0.3 sec about two months before a magnitude 5.0 earthquake that occurred within a few kilometers of the station. This indicates that velocity changes, observed elsewhere premonitory to earthquakes and possibly related to dilatancy, occur along the central section of the San Andreas fault system.

● 2.8-9 Usami, T., **Earthquake studies and the earthquake prediction system in Japan,** *Technocrat,* **7,** *3,* Mar. 1974, 81-98.

The history of Japanese earthquake prediction is outlined and the measurements taken by Japanese researchers to predict earthquakes are described. Some of the specific measurements and observations discussed are geodetic measurements, tide-gauge observations, observations of crustal deformation, recordings of earthquakes and microearthquakes, ocean-bottom seismometer observations and gravity measurements. In the final section of the paper, a test case of the prediction of future earthquakes off the Nemuro Peninsula and the problems associated with earthquake prediction in general are reviewed.

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● **2.8-10** Ryall, A. and Savage, W. U., ***S*-wave splitting: Key to earthquake prediction?**, *Bulletin of the Seismological Society of America*, **64**, *6*, Dec. 1974, 1943-1951.

This paper presents a detailed analysis of S-wave data for two areas in western Nevada. Some of these data were used by Gupta as the basis for his claim that large premonitory changes in the extent of stress-induced S-wave splitting are observed for moderate-sized earthquakes in Nevada. Analysis of particle motion for an earthquake sequence near Slate Mountain indicates that changes in S-wave splitting did not occur during that sequence. For the Mina area, comparison of S-wave signatures for 158 events occurring over a 3-year period resulted in the identification of numerous events that would be considered anomalous by Gupta's criteria, but these were not followed by larger earthquakes. The present state of knowledge on crustal structure and seismic source parameters in the western Basin and Range province is not sufficient to discriminate between stress-induced velocity anisotropy and the many other factors that contribute to the complexity of S-wave signatures.

2.8-11 Utsu, T., **Detection of a domain of decreased *P*-velocity prior to an earthquake** (*in Japanese*), *Zisin, Journal of the Seismological Society of Japan*, **28**, *4*, Dec. 1975, 435-448.

About 400 shallow earthquakes that occurred in central Japan during 1967-1974 were relocated using data supplied by the Japan Meteorological Agency and several university seismic stations. About 4200 *P*-residuals were obtained in the relocation. The residuals are approximately normally distributed with a mean of 0.0 sec and a standard deviation of 0.59 sec. Therefore, the probability that a residual exceeds 0.4 sec is 0.25. If the actual travel-time for paths crossing the focal region of an impending earthquake is increased by 0.4 sec, the probability that an observed residual for one of these paths exceeds 0.4 sec will be 0.50. *R* denotes the ratio of the number of paths with residuals larger than 0.4 sec to the total number of the paths crossing a certain region. The *R*-values for the focal regions of the central Gifu earthquake of 1969 ($M = 6.6$), the Izuhanto-oki earthquake of 1974 ($M = 6.9$), and 24 other earthquakes of smaller magnitudes during certain time intervals prior to the occurrence of the earthquakes were determined to be about 0.5 or more. These values suggest a decrease in *P*-velocity before the earthquakes. A map was made, showing the distribution of *R*-values in 204 areas of 0.2° x 0.2° in central Japan. Significantly high *R*-values are found in the areas containing the focal regions of the two above-mentioned earthquakes. However, many other areas of high *R*-values have not been associated with the occurrence of large earthquakes until recently. Most of these latter areas may correspond to inherent low-velocity regions in the crust.

● **2.8-12** Hasegawa, A., Hasegawa, T. and Hori, S., **Premonitory variation in seismic velocity related to the southeastern Akita earthquake of 1970**, *Journal of Physics of the Earth*, **23**, *2*, 1975, 189-203.

Premonitory change in the ratio of compressional and shear wave velocities was observed for the shallow earthquake of magnitude 6.2 that occurred in the southeastern part of Akita Prefecture in northeastern Japan on Oct. 16, 1970. The time duration of the anomalous velocity preceding this earthquake was about two years, the value being in good accordance with the period expected from the relationship between earthquake magnitude and precursory time interval based on the dilatancy model. The size of the anomalous region, in this case, was estimated to be about two times as large as the aftershock area.

The temporal variations of the *b* value in the earthquake frequency-magnitude relation and the seismic activity near the focal region were also investigated. A positive correlation was obtained between the *b* value and the velocity ratio of compressional and shear waves. A remarkable foreshock activity was observed just after the recovery of seismic wave velocity to the normal value.

● **2.8-13** Stewart, D. M., **Possible precursors of a major earthquake centered near Wilmington-Southport, North Carolina**, *Earthquake Notes*, **46**, *4*, Oct.-Dec. 1975, 3-19.

The author presents evidence of a land rise anomaly near Wilmington-Southport, which has averaged 6.5 mm per year for the period 1932-1962. Failing to find other plausible reasons for the rise, the author postulates deep stresses in the basement rock as the cause. Since the seismicity of the area is indistinguishable from that of Charleston prior to 1886, it is concluded that an earthquake similar to the Charleston event of 1886 is possible in the area. It is estimated that the magnitude of the earthquake will be approximately 7.0. Instrumentation in the area has been augmented in an attempt to gather more definitive information on the anomaly.

● **2.8-14** Boore, D. M. *et al.*, **A search for travel-time changes associated with the Parkfield, California, earthquake of 1966**, *Bulletin of the Seismological Society of America*, **65**, *5*, Oct. 1975, 1407-1418.

Studies of *P*-wave travel times at a station within 0.5 km of the ground rupture associated with the Parkfield, California, earthquake of 1966 show no systematic variations for a time period of 7 months before the mainshock to at least 13 months after the event. Sources used include quarry blasts, regional earthquakes, explosions at the Nevada Test Site (NTS), and teleseismic earthquakes. The data from the quarry blasts and regional earthquakes have a scatter of less than ± 0.15 sec. With suitable source corrections, the scatter in the NTS data can be reduced to

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about ±0.25 sec (making the catalog of nuclear explosions potentially useful for monitoring large travel-time changes). The data from teleseismic *P* waves have much more scatter than do the data from the more local sources.

The regional earthquake data (expressed as the time differences between the station near the ground rupture and one farther to the north) show temporal variations, but these variations appear to be due to systematic changes in the hypocentral locations of the sources rather than changes in the seismic velocity near the recording stations. The quarry blasts are not as subject to this bias and consequently are more reliable for the monitoring of seismic velocity changes.

The negative results of the study do not rule out the possibility that a velocity anomaly was associated with the Parkfield earthquake; they do, however, require that any velocity change as large as 15 per cent be confined to a volume that is either less than about 5 km deep by several kilometers wide or that does not coincide spatially with the rupture zone.

● 2.8-15 Gupta, I. N., **Premonitory changes in t_s/t_p due to anisotropy and migration of hypocenters**, *Bulletin of the Seismological Society of America*, **65**, *5*, Oct. 1975, 1487-1493.

The anisotropic characteristics of stress-induced cracks in dilatant rock can significantly influence the observed values of t_s/t_p obtained using the Wadati diagram. Systematic vertical migration of hypocenters of foreshocks within a region of thrust tectonics can lead to variations in both t_s/t_p and orientation of the compressive stress axis of the same type as observed before several thrust-type earthquakes. In this model, the seismic velocities become considerably anisotropic due to preferential alignment of open cracks, but it is not essential to assume pre-earthquake flow of groundwater into the dilated zone. Observations of t_s/t_p versus depth of focus in the Garm region, U.S.S.R. and some other results appear to support this possibility.

● 2.8-16 Rikitake, T., **Earthquake precursors**, *Bulletin of the Seismological Society of America*, **65**, *5*, Oct. 1975, 1133-1162.

An analysis of existing earthquake precursor data leads to a conclusion that the precursors reported so far can be classified into three types, i.e., A_1, A_2 and B types. Most of type B precursors, observed in terms of anomalous tilts and strains or foreshocks, have no magnitude-dependent precursor time. Meanwhile the A_2-type precursors observed by means of geodetic work, changes in seismic-wave velocities and the like seem to have a precursor time which is closely correlated to the magnitude of coming earthquakes. A precursor of this type may possibly be interpreted by the current theory of dilatancy. The A_1-type precursors, observed mostly several hours prior to the main shock, may be caused by a creeplike failure before the main rupture of the earth's crust.

Probabilities for an anomalous signal of various geophysical elements to be related to a forthcoming earthquake are estimated on the basis of the existing data of precursors.

A feasible strategy for predicting a large earthquake as suggested by the present study would be as follows: First of all, the accumulation of crustal strain is monitored by means of geodetic work. The next task is to detect an A_2 signal which would arise from a highly strained crust sooner or later. If the spatial extent of the A_2-type precursor is known, it is possible to estimate roughly the magnitude as well as the occurrence time of the coming earthquake. Finally, detection of an A_1-type precursor, if it should occur, would provide a short-range forecast having a time span of hours.

2.8-17 Vinogradov, S. D., Mirzoyev, K. M. and Salomov, N. G., **Time distribution of elastic shocks during fracture of specimens**, *Physics of the Solid Earth*, **11**, *4*, Nov. 1975, 221-224.

Investigation of the time distribution of the elastic shocks that arise during the deformation and fracture of specimens has shown that it depends appreciably upon the deformation rate. At a low deformation rate, a period of calm (absence of elastic shocks) is observed prior to the appearance of the major fracture (i.e., before complete failure of the specimen) under conditions of quasiviscous flow. A similar lull is observed before rock bursts and earthquakes. This makes it possible to interpret the form of the change in the velocity ratio V_P/V_S before earthquakes.

● 2.8-18 Papazachos, B. C., **Foreshocks and earthquake prediction**, *Tectonophysics*, **28**, *4*, Nov. 1975, 213-226.

Results of a statistical investigation of the magnitude and time distributions of foreshocks in the area of Greece are reported. Further evidence is presented that the parameter b, in the frequency-magnitude relation, has a smaller value before than after the main shock, and that the time distribution of foreshocks follows a statistical law similar to that followed by aftershocks. The difference in magnitude between the main shock and the largest foreshock seems to be independent of the magnitude of the main shock. The average of this difference has been found equal to about two magnitude units. The significance of these results to the problem of statistical prediction of earthquakes is noted.

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● **2.8-19** Ando, M., **Possibility of a major earthquake in the Tokai District, Japan and its pre-estimated seismotectonic effects**, *Tectonophysics*, **25**, *1/2*, Jan. 1975, 69-85.

Crustal deformations, tsunamis and seismic intensity are pre-estimated for a large hypothetical earthquake, which it is feared may occur in the Tokai district along the Nankai trough. The long-term seismic quiescence since 1854, as well as the high rate of the present crustal movements in the district, forms the principal evidence for the risk of the approaching catastrophe. The location and the mode of faulting in this earthquake are hypothesized with reference to the source mechanisms of the recent and historical earthquakes there. The fault parameters thus assumed are as follows: dip direction: N30°W; dip angle: 25°; fault dimension: 100 km X 70 km; dislocation: 4 m (reverse dip-slip: 3.8 m; right-lateral strike-slip: 1.3 m). The following are the principal conclusions: (a) the eastern part of the epicentral region including the Point Omaezaki will rise up about 100 cm, whereas the western part covering Ise and Mikawa bays will subside about 10-30 cm; (b) the coast extending from Omaezaki to the Shima peninsula will receive tsunami waves as high as 3 m in maximum, which may be locally amplified by the factor 2 or more on the coast along the Shima peninsula; (c) the Tokai coastal region with thick alluvium layers may suffer seismic damages as severe as those experienced in the 1854 Ansei I earthquake.

● **2.8-20** Savage, J. C., Church, J. P. and Prescott, W. H., **Geodetic measurement of deformation in Owens Valley, California**, *Bulletin of the Seismological Society of America*, **65**, *4*, Aug. 1975, 865-874.

Repeated (1934, 1956, and 1974) geodetic surveys across Owens Valley near the site of the 1872 earthquake indicate right-lateral deformation at the rate of 4 ± 1 mm/yr and possible extension across the valley at the rate of 1 ± 1 mm/yr. Repeated level surveys across the valley indicate a down-to-the-east tilt of about 0.22 ± 0.04 μradians/yr for the western block with a hinge line near the rupture trace of the 1872 earthquake. This tilt is equivalent to an uplift of the west edge of the valley of 2.2 ± 0.4 mm/yr (i.e., base of the Sierra Nevada scarp) relative to the center of the valley. Although the measured deformations are scarcely above survey noise, they all indicate an accumulation of strain which would be consistent with a repeat of the 1872 earthquake (normal, right-lateral oblique slip).

2.8-21 Kropotkin, P. N. and Lyustikh, A. E., **Seasonal periodicity of earthquakes and the Newton-Mach principle** (Sezonnaya periodichnost zemletryasenii i printsip Nyutona-Makha, in Russian), *Doklady AN SSSR*, **217**, *5*, 1974, 1061-1064.

Statistical analysis of data on earthquake frequencies in various months of the year (using 9665 earthquakes over the years 1904-1965) shows a seasonal periodicity. On a curve which was smoothed using the moving average method the frequency is maximal in June and minimal in January, and the curve is approximately a sine curve with amplitude = 10%. According to the Dicke hypothesis, the most likely reason for this periodicity is the variation in the radius of the earth due to a relativistic change in the active gravitational mass of the earth.

2.8-22 Oike, K., Shichi, R. and Asada, T., **Earthquake prediction in the People's Republic of China** (in Japanese), *Zisin, Journal of the Seismological Society of Japan*, **28**, *1*, Mar. 1975, 75-94.

The present state of seismology, and especially the prediction of earthquakes, in the People's Republic of China is reported, along with a brief description of a July 1974 visit. Seismological investigations are more highly developed than expected. Disasters caused by several severe earthquakes in recent years have resulted in the formation of cooperative activities for earthquake prediction. A network system for observation of earthquakes, centered at the Inst. of Geophysics at Peking, now covers the entire continent. About 200 researchers at the institute are engaged in earthquake research. Several current earthquake prediction research programs are described.

2.8-23 Hisamoto, S., **An investigation of V_P/V_S observed at Abashiri, Hokkaido** (in Japanese), *Zisin, Journal of the Seismological Society of Japan*, **28**, *1*, Mar. 1975, 41-49.

The earthquake, which occurred near Teshikaga, on Nov. 4, 1967, was accompanied by slight property damage in Teshikaga and vicinity. It is found that V_P/V_S observed at Abashiri Meteorological Observatory for earthquakes which occurred in the Teshikaga-Akan area, showed unusually low values prior to the above-mentioned earthquake, and returned to the normal value after the earthquake. This result is discussed briefly in relation to the dilatancy theory of earthquakes developed by Scholz and others.

2.8-24 Yamazaki, Y., **A detectability of the resistivity variometer system at Aburatsubo** (in Japanese), *Transactions of the Architectural Institute of Japan*, **28**, *1*, Mar. 1975, 31-40.

A resistivity variometer has been in use at Aburatsubo in Kanagawa Prefecture, about 60 km south of Tokyo, since May 14, 1968. During the 6-year period up to June 30, 1974, more than 25 records of coseismic resistivity changes have been obtained in association with large earthquakes. The major results have already been summarized by the author.

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This paper presents a conclusion concerning the detectability of the variometer system. The magnitude (M) of each earthquake that occurred during the 6 years was plotted against logarithmic epicentral distance (Δ). Almost all earthquakes for which coseismic resistivity changes were observed fell on the upper boundary of the line $M = 2.5\log_{10}\Delta$, where Δ was measured in kilometers. With the use of Wideman and Major's strain and epicentral distance relation, the variometer can detect a strain change of the order of 10^{-9}. At the same time, this indicates that a small strain of the earth of the order of 10^{-8} can be detected by the variometer with a magnification factor of approximately 10^4.

2.9 Special Topics

● 2.9-1 Udias, A. and Rice, J., **Statistical analysis of microearthquake activity near San Andreas Geophysical Observatory, Hollister, California**, *Bulletin of the Seismological Society of America*, 65, *4*, Aug. 1975, 809–827.

Microearthquake activity during the four-year interval 1968 to 1971 in a region of 25 km radius, centered on the San Andreas Fault near Hollister, has been monitored by means of high-gain high-frequency seismographs which allow detection of events as small as magnitude zero within the region. The distribution of the 4764 microearthquakes shows a high degree of clustering. The series of time intervals between consecutive shocks can be described approximately by a gamma distribution whose shape parameters for different samples change from 0.3 to 0.8. The exponential probability plots of the $\{\Delta t_i\}$ series for 265 larger regional earthquakes over 10 years result in a constant value of the hazard function except for small values of time where the hazard is higher. The variance-time and intensity functions show a varying degree of interdependence between events for each year and a long-term dependence up to 80 days for the period 1968–1971. The time scale of clustering has been estimated. Inferences based on short-term microearthquake studies may be grossly misleading.

● 2.9-2 King, D. and Helmberger, D. V., **Time functions appropriate for some aftershocks of the Point Mugu, California earthquake of February 21, 1973**, *Bulletin of the Seismological Society of America*, **65**, *1*, Feb. 1975, 127–132.

Broad-band recordings of aftershocks of the Pt. Mugu earthquake at small epicentral distances provided an excellent opportunity to test source models for small earthquakes. Simple events recorded at nearly vertical incidence produced a single *P*-wave pulse of a duration of about 0.07 sec and a somewhat more complicated S-wave with a slightly longer duration. Such events are consistent with a point dislocation source for which $Q\beta = 100$ or for which there is directivity with the fault breaking downward. We attribute the more usual complexities of small earthquake records to multiple events, some of which we observed, layering effects combined with greater epicentral distances, and scattering.

● 2.9-3 King, C.-Y., **Model seismicity and faulting parameters**, *Bulletin of the Seismological Society of America*, **65**, *1*, Feb. 1975, 245–259.

A frictional sliding model consisting of lumped masses and elastic springs has been constructed to simulate a seismic strike-slip fault. The model was capable of generating stick-slip events with some statistical features similar to those of natural earthquakes. The patterns of strain buildup and release associated with a long sequence of shocks are described in the hope that they may reflect to some extent the behavior of a real seismic fault: (1) Shocks of greatly different sizes were generated, although the friction inhomogeneity along the fault was small. (2) The recurrence relation for the shock sequence resembled that for earthquakes. (3) Large shocks occurred at irregular time intervals and released most of the strain energy of the sequence. (4) The logarithm of the product of average particle displacement and rupture length increased linearly with shock size (logarithm of strain-energy release). (5) Shocks of the same rupture length sometimes had considerably different particle displacements. (6) The shear stress drops increased with shock size from about 1 per cent of the preshock stress for small shocks to 40 per cent for the largest shock; the occurrence of small and moderate shocks did not greatly perturb the operating stress level. (7) The preshock stresses and energy densities along the ruptured segments did not increase much with the shock size; larger shocks occurred mainly when a longer segment of the fault was stressed simultaneously to near the breaking level. (8) Ruptures preferred to propagate in the forward direction owing to a built-in asymmetry of the model fault. (9) Particle displacements were approximately finite ramp functions of time with periods of acceleration at the beginning and deceleration at the end. (10) Particle velocities increased with particle displacements, ranging from 2 to nearly 30 cm sec^{-1}. (11) Rupture propagation velocities scattered considerably but tended to increase slightly with rupture length. (12) Aftershocks were few but occasionally occurred at places where slippage was small during the main shocks. The lack of a significant number of aftershocks in the model probably results from the absence of such time-dependent elements as viscosity or moving pore fluids that operate along natural faults.

2.9-4 Hadley, K., **Azimuthal variation of dilatancy**, *Journal of Geophysical Research*, **80**, *35*, Dec. 10, 1975, 4845–4850.

In triaxial laboratory tests, variation of circumferential strain in dilatant granite may reach 100% or more at high stresses. Pseudoelastic compliances s_{13} and s_{23} in the

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plane perpendicular to the maximum stress may differ by a factor of 2–10. Given the magnitude of these differences, in situ azimuthal variation of dilatancy should be the observed rule rather than the exception. Such anisotropy might be exploited to determine the strike of a future fault break or the next site of fault motion.

2.9-5 Helmberger, D. V. and Malone, S. D., **Modeling local earthquakes as shear dislocations in a layered half space,** *Journal of Geophysical Research,* **80**, *35*, Dec. 10, 1975, 4881–4888.

The *SH* impulse response of layered medium resulting from the application of a point source shear dislocation is studied by the generalized ray technique. Numerical seismograms of ground displacement in the range 10–100 km are constructed for a number of different crustal models and source descriptions. The results for shallow events show severe wave form modifications at epicentral distances as small as twice the source depth when models contain soft surface layers. A comparison of synthetic seismograms with observations from a central California earthquake of magnitude 4.6 indicates a moment of 2.1 x 10^{22} ergs with a faulting duration of 0.5 sec. This moment is noticeably smaller than that estimated from the low-frequency level of the whole seismogram spectrum assuming the usual homogeneous halfspace model. This occurs because the energy arriving with the surface waves and deep crustal reflections boosts the long-period portion of the spectrum, giving the impression of an anomalously large moment when calculated in the conventional manner. The close agreement between synthetic results and the actual data both in the time and in the Fourier transform domain suggests that the authors' deterministic approach can be quite useful in understanding the complexity of seismograms recorded in the local field.

2.9-6 Vinogradov, S. D., Mirzoyev, K. M. and Solomov, N. G., **Time sequences of elastic pulses during the fracture of rock samples under constant load,** *Physics of the Solid Earth, 7,* July 1974, 430–434.

Experiments involving the fracture of rock samples under a constant load are discussed. The samples were deformed under conditions of quasiviscous flow with a deformation rate of 10^{-9} sec^{-1}. The time distribution of the elastic pulses arising from the process of deformation and fracture of the samples is different from that arising under conditions of increasing load. An increase of the number of pulses was not observed before the fracture.

2.9-7 Shemyakin, Ye. I. and Shcheglov, V. I., **A study of the movement mechanism during crustal earthquakes,** *Physics of the Solid Earth, 12,* Dec. 1974, 795–800.

The question of the nature and mechanism of crustal earthquakes is discussed. It is hypothesized that there exist in the earth's crust two zones of seismic activity concentration which are related to the physical properties of the material. The upper zone (depths of 3–5 km) corresponds to the pressure at which the pores in rocks close. The lower zone (depths of 8–15 km) is related to the critical conditions for aqueous solutions contained in the crust. An elastoplastic model of the behavior of rock near the edge of a shear crack is considered. In the proposed model, the stresses and strains at the edge of the crack are finite. They accumulate slowly; then during fracture (an earthquake), elastic unloading occurs.

● **2.9-8** Hays, W. W., Algermissen, S. T. and Duke, C. M., **Use of aftershock ground motion data in earthquake engineering,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 60–69.

Special purpose seismic arrays were deployed following the 1971 San Fernando, California, and the 1972 Managua, Nicaragua, earthquakes. The objective was to obtain data which could be used to evaluate the usefulness of aftershock ground motion data in ground motion research studies. Portable broad-band systems recording velocity on magnetic tape were used in each seismic array. The principal criterion used in deployment was that the ground motion records of the aftershock sequence be obtained at sites which either recorded the main shock or were located in the region of strong shaking and damage where no main shock recording existed. Particle velocity records of the San Fernando aftershock sequence were obtained at 100 different locations (e.g., Pacoima Dam, Holiday Inn, Bank of California, Glendale) during approximately a four-month period. The Managua aftershock sequence was recorded at 18 different locations throughout the city (e.g., Esso Refinery, Banco Central) during a period of approximately one month.

2.9-9 **Magnitude and energy classification of earthquakes** (Magnituda i energeticheskaya klassifikatsiya zemletryasenii, in Russian), Inst. of the Physics of the Earth, Academy of Sciences of the U.S.S.R., Moscow, 1974, 2 vols., 220.

The contents of the two volumes reflect the present state of problems involved in the classification of the magnitudes and energy of earthquakes. An analysis of the physical foundations of calculating magnitudes is given. The nature and purpose of various magnitude scales are discussed. Quantitative changes in field spectra of seismic ground motion with earthquake parameters are studied. Careful attention is paid to methodological questions related to calculations of magnitude from body and surface waves.

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● **2.9-10** Gupta, I. N., **Dilatancy and spatial distribution of aftershocks,** *Bulletin of the Seismological Society of America,* **64,** *6,* Dec. 1974, 1707-1713.

The pre-earthquake dilatancy, postulated to explain certain premonitory seismic velocity changes, may provide a preferred direction of groundwater flow persisting after the occurrence of a shallow earthquake. This direction is parallel to and nearly coincident with the compressive stress axis associated with the focal mechanism of the principal shock. Aftershocks may result from a redistribution of pore pressure and fluid flow not only along faults but also along this direction of relatively large permeability. This suggestion provides a possible explanation for certain observations of aftershocks aligned along the compressive stress direction.

● **2.9-11** Shteinberg, V. V., Kramynin, P. I. and Aptekman, Zh. Ya., **The aftershocks of the May 14, 1970 Dagestan earthquake** (Kharakter povtornykh tolchkov Dagestanskogo zemletryasniya 14 maya 1970. g., in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 39-52.

The several hundred aftershocks following the May 14, 1970, Dagestan earthquake are analyzed. Two groups of aftershocks with differing seismographic patterns are isolated.

● **2.9-12** Bollinger, G. A., **A microearthquake survey of the central Virginia seismic zone,** *Earthquake Notes,* **46,** *1-2,* Jan.-June 1975, 3-14.

The central Virginia seismic zone is an example of a transverse seismic zone exhibiting a low level of activity. To investigate what level of microseismicity would be associated with such a zone, some 2200 low-noise hours of data were collected at 26 different locations throughout the zone. This monitoring program, complete down to about zero magnitude, recorded several definite and four probable microearthquakes. This low rate of occurrence of one event every eight days seems to be in accord with the area's macroseismicity (M>3) over the past 45 years.

2.9-13 Sharma, H. S. S. and Murty, G. S., **A statistical study of Koyna aftershocks for the period January 1968-October 1973,** *Indian Journal of Meteorology, Hydrology and Geophysics,* **26,** *1,* 1975, 121-126.

A statistical study was made of aftershocks from the Koyna region in order to find the time dependence of energy release. A total of 210 aftershocks recorded at the Gauribidanur seismic array from Jan. 1968 to Oct. 1973 were analyzed. Most of the aftershock magnitudes ranged from 3.8 to 5.8. Apart from some fluctuations, the cumulative energy release in this period shows a tendency to vary as the square root of time that elapsed after Jan. 1968.

2.9-14 Johnson, T. L., **A comparison of frictional sliding on granite and dunite surfaces,** *Journal of Geophysical Research,* **80,** *17,* June 10, 1975, 2600-2605.

Frictional motion on ground sliding surfaces of Westerly granite, Twin Sisters dunite, and Spruce Pine dunite and on the various combinations of these rocks was studied. Stable and episodic sliding and stick slip motion were observed for all combinations of Westerly granite and Twin Sisters dunite. Stick slip was observed when Spruce Pine dunite slid on granite or on Twin Sisters dunite, but only stable sliding and episodic sliding were observed when Spruce Pine dunite slid on itself. There are systematic differences in the frictional behavior of the different lithologies and also in the effects of different types of gouge. Prestick slip creep was observed before all events and thus may be characteristic of stick slip.

● **2.9-15** Talwani, P., Secor, D. T. and Scheffler, P., **Preliminary results of aftershock studies following the 2 August 1974 South Carolina earthquake,** *Earthquake Notes,* **46,** *4,* Oct.-Dec. 1975, 21-28.

Aftershock studies following the Aug. 2, 1974, earthquake in McCormick County, South Carolina, indicate continuing seismic activity with a pattern of increasing and decreasing seismicity near the Clark Hill Reservoir. The shallow earthquakes have a predominantly strike-slip motion, with the strike direction along the Appalachian trend. The activity appears to be associated with temporal velocity changes and bears several similarities to seismic activity near the Blue Mountain Lake area, New York.

● **2.9-16** Mkhitaryan, L. A., **Results obtained with multipendulum seismometers in investigations of the Dagestan earthquake of May 14, 1970** (Rezultaty poluchennye mnogomayatnikovymi seismometrami pri izuchenii Dagestanskogo zemletryaseniya 14 maya 1970 g., in Russian), *Byulleten po inzhenernoi seismologii, 9,* 1975, 111-113.

Problems of instrumental investigations of the characteristics of the aftershocks of the Dagestan earthquake of May 14, 1970, are discussed. Dominant periods are calculated from instrumental data.

● **2.9-17** Herrmann, R. B. and Nuttli, O. W., **Ground-motion modelling at regional distances for earthquakes in a continental interior, I. Theory and observations,** *International Journal of Earthquake Engineering and Structural Dynamics,* **4,** *1,* July-Sept. 1975, 49-58.

To understand the ground-motion contribution by multiple-mode surface-wave arrivals, the surface-wave theory required for predicting ground-motion time histories is discussed. The adequacy of the theory in accounting for observed earthquake ground motion is tested by comparing theoretically predicted long-period seismograms with real

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seismograms for two earthquakes in the central United States. The agreement between the predicted and observed maximum vertical component L_g ground velocities and accelerations in the 2- to 3-sec period range is excellent over a distance range of 100 to 2000 km.

● 2.9-18 Herrmann, R. B. and Nuttli, O. W., **Ground-motion modelling at regional distances for earthquakes in a continental interior, II. Effect of focal depth, azimuth and attenuation,** *International Journal of Earthquake Engineering and Structural Dynamics,* **4,** *1,* July-Sept. 1975, 59-72.

Multiple-mode surface-wave signals are used to model ground motion at distances of 50 to 500 km for an earthquake source in a continental interior. Motion on a thrust fault is used as the earthquake model. Theoretical ground-motion time histories are generated for this source for various focal depths, receiver azimuths and medium-attenuation models. A shallow source will generate greater values for the ground motion than the same source at a greater depth. Two anelastic attenuation models are considered, one appropriate to the central and eastern United States and the other to southern California. The effects of the difference in the attenuation models are seen at distances greater than 100 km for periods greater than 1.5 sec.

● 2.9-19 Archuleta, R. J. and Brune, J. N., **Surface strong motion associated with a stick-slip event in a foam rubber model of earthquakes,** *Bulletin of the Seismological Society of America,* **65,** *5,* Oct. 1975, 1059-1071.

In this paper, the authors present and interpret dynamic displacement data for a stick-slip event in a foam rubber model of earthquake faulting. Static displacement data are used to infer the stress drop of about 0.016 μ, where μ is the shear modulus. The rupture velocity 0.7 β, where β is the shear-wave speed, is also inferred from the data. The observed particle displacement and particle velocity data are compared with analytical and numerical predictions. Doppler focusing of energy by rupture propagation is clearly observed. No large transverse displacement pulse such as that observed at Station 2 of the Parkfield earthquake is observed. In addition to its value for testing analytical and numerical predictions, the laboratory model provides much needed information on the distribution of strong ground motion in the neighborhood of a fault and thus helps in the problem of microzonation for earthquakes.

● 2.9-20 Johnston, M. J. S. *et al.,* **A possible seismomagnetic observation on the Garlock Fault, California,** *Bulletin of the Seismological Society of America,* **65,** *5,* Oct. 1975, 1129-1132.

Simultaneous measurements of geomagnetic fields have been made at pairs of sites approximately 12 km apart along the Garlock Fault. On June 9 and 10, 1974, several minor earthquakes (M = 2.6 to 4.3) occurred near one of these sites 3 weeks after the first measurements were made. Two repeated data sets were taken 2 weeks and 3 months after the earthquakes. The differenced data indicate that, relative to pre-earthquake values, the local magnetic field at this site had increased by about 2γ. A piezomagnetic source for this change implies a stress change that would exceed 10 bars. After 3 months the same form of anomaly still remained although larger in spatial scale. This might indicate dispersion of the stress discontinuities produced by the earthquake.

● 2.9-21 Stewart, I. C. F., **A magnitude scale for local earthquakes in South Australia,** *Bulletin of the Seismological Society of America,* **65,** *5,* Oct. 1975, 1267-1285.

To minimize dispersion in local magnitude estimates due to different instrumental bandwidths, a scale has been established to allow for the average source spectrum, geometrical attenuation, and frequency-dependent absorption. The data used to derive the scale parameters were from S waves, recorded in South Australia from 1967 through 1970, in the frequency range 1 to 10 Hz, and for epicentral distances up to 5°. The magnitudes were mainly in the range 1.5 to 3.5.

The dispersion in observations of magnitude has probably been reduced by use of the scale to near the theoretical limits, allowing for possible source radiation patterns. The relationship of the scale to other measures of magnitude is uncertain, but the scale may be approximately equivalent to the local Richter magnitude M_L for the magnitude range ($1.5 < M_L < 3.5$), commonly observed in South Australia.

The scale is limited in use to data in the ranges given above for local earthquakes in South Australia. Modification is necessary before such a magnitude scale can be applied elsewhere or to different data ranges.

● 2.9-22 Singh, S. K. and Sabina, F. J., **Epicentral deformation based on the dilatancy-fluid diffusion model,** *Bulletin of the Seismological Society of America,* **65,** *4,* Aug. 1975, 845-854.

The dilatancy-fluid diffusion model of the earthquake mechanism implies deformation of the epicentral area. Based on a result in the theory of thermoelasticity, the authors present a method for computing such deformation. Details are given for a dilating sphere and a dilating infinite cylinder buried in an elastic halfspace. Given the volumetric strain of the dilatant region, the deformation measurements could be used to estimate the magnitude of the impending earthquake. Alternatively, a constraint on

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the volumetric strain can be obtained from deformation measurements before earthquakes that are preceded by dilatancy.

2.9-23 Matsuda, T., **Magnitude and recurrence interval of earthquakes from a fault** (in Japanese), *Zisin, Journal of the Seismological Society of Japan,* 28, 3, Oct. 1975, 269-283.

The recurrence interval (R) of earthquakes from a given fault-segment is related to the long-term slip-rate (S) and the displacement (D) accompanying an earthquake. The relation is expressed as $R = D/S$, when aseismic fault creep is disregarded. D has a relation with the earthquake magnitude M as $\log D(\text{meter}) = 0.6M-4.0$ for Japanese inland earthquakes. Then, the relation R to M is expressed as $\log R = 0.6M-4.0-\log S$.

It is proposed here that a given fault segment has a constant value of D through time during the late Quaternary period. Values of D and M may be different between different fault segments, but there are specific values for a given fault or its segment. Historic records on Japanese earthquakes seem consistent with this assumption. Values of D or M are obtained from data of historic earthquakes or from a unit offset of geologic references.

Fault length L is proportional to a dimension of strain domain, and it represents the maximum magnitude from the fault. The relation of L to earthquake magnitude M is $\log L$ (kilometer) $= 0.6M-2.9$ for Japanese inland earthquakes. Then, maximum magnitude from a fault is expressed as $(1/0.6)\log L + 4.85$.

When a given fault or its segment has no earthquake during at least t years up to the present, the accumulated earthquake energy during t years is expressed as $(1/0.6)\log(t \cdot S) + 6.67$. Thus, a probable maximum magnitude from a given fault or its segment lies between the accumulated energy during t years and the maximum magnitude.

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3. Engineering Seismology

3.1 General

3.1-1 Nazarov, A. G., **The fundamental problem of engineering seismology** (Osnovnaya problema inzhenernoi seismologii, in Russian), *Byulletin po inzhenernoi seismologii, 8,* 1973, 5-9.

Various problems in engineering seismology, such as those relating to the construction of seismic scales using instrumental data and those relating to seismic zoning and microzoning, are considered. Problems associated with the measurement of seismic intensities and with earthquake-resistant structural design also are discussed. The central problem of engineering seismology is that of selecting a set of strong-motion accelerograms which can be expected at various surface locations.

● 3.1-2 Howell, Jr., B. F. and Schultz, T. R., **Attenuation of Modified Mercalli intensity with distance from the epicenter,** *Bulletin of the Seismological Society of America,* **65**, *3,* June 1975, 651-665.

Thirteen simple formulas describing the attenuation of Modified Mercalli (MM) intensity are compared to determine which best predicts observed values in North America. The equation

$$\ln I = \ln I_o + a_2 - b_2 \ln\Delta - c_2\Delta$$

based on the assumption that intensity is related to energy by the equation

$$I = kE^P$$

appears to be the most useful, although it is not the most precise. P was found to be approximately 1/6, indicating that MM intensity is proportional to the sixth root of energy or the cube root of amplitude.

The United States and southern Canada are divided into three attenuation provinces: a San Andreas province with an energy absorption coefficient of 0.015/km, an Eastern province with an absorption coefficient of 0.0031/km and a Cordilleran province with an absorption coefficient of 0.0063/km.

The different rates of absorption can be explained as the result of slightly greater average focal depths in the East than in the West, although the data are too scattered to prove that this is the cause. Greater depth of focus, especially if low-angle faulting is involved, would explain the lack of surface displacement with eastern earthquakes.

● 3.1-3 Housner, G. W., **Measures of severity of earthquake ground shaking,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 25-33.

Some of the common measures of intensity are discussed and their shortcomings described. It is pointed out that an adequate engineering measure of earthquake severity cannot be described by a single parameter but requires at least two. These two parameters could be the spectrum intensity plus the duration of strong shaking, or they could be the average power of the input during the strong phase of shaking plus the duration of that input.

● 3.1-4 **Satellites helping solve down-to-earth civil engineering problems,** *Civil Engineering, ASCE,* **45**, *8,* Aug. 1975, 49-53.

With its ERTS (Earth Resources Technology Satellite) and other satellites and U2 high-flying aircraft, NASA is generating much remote-sensing information about the condition of the atmosphere, earth and oceans. Much of this information is being used in civil engineering applications. NASA is seeking feedback from civil engineers about what they like and don't like about the space agency's

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remote sensing program. Efforts are under way to make the program more relevant to civilian needs.

● 3.1-5 Karapetyan, N. K., **On the role of the seismological characteristics of earthquakes in construction of seismic intensity scale** (Ob uchete seismologicheskikh kharakteristrik zemletryasenii pri sostavlenii shkaly ballnosti, in Russian), *Byulleten po inzhenernoi seismologii*, 9, 1975, 32–45.

The role of seismological characteristics in constructing a new seismic scale is discussed. The usefulness of simultaneous seismological and engineering investigations is demonstrated using the aftershocks of the 1968 Zangezour earthquake.

● 3.1-6 Nechaev, V. A., **Ground acceleration scale and the effects of ground motion on structures** (Shkala uskorenii seismicheskikh kolebanii grunta i ikh vozdeistvie na sooruzheniya, in Russian), *Byulleten po inzhenernoi seismologii*, 9, 1975, 19–31.

The history of the construction of seismic scales is discussed and the foundations of a new seismic scale based on the variation of intensity with the acceleration and velocity of ground motion and building response are presented. The new and old scales are compared and differences between them calculated.

● 3.1-7 Karapetyan, B. K., **Calculation of earthquake magnitude from macroseismic effects on earthquake-resistant buildings** (Ustanovlenie sily zemletryaseniya po makroseismicheskim obsledovaniyam seismostoikikh zdanii, in Russian), *Byulleten po inzhenernoi seismologii*, 9, 1975, 15–18.

At present earthquake intensities are calculated in part from macroseismic observations of damaged buildings that are not earthquake resistant. Various methods for determining magnitudes from the response of earthquake-resistant buildings are explored.

● 3.1-8 Evernden, J. F., **Seismic intensities, size of earthquakes and related parameters**, *Bulletin of the Seismological Society of America*, 65, 5, Oct. 1975, 1287–1313.

The simple model of an earthquake used in Evernden *et al.* (1973) was extended to the conterminous United States and observed patterns of isoseismals for major earthquakes studied in relation to the model. Regional attenuation, a known major factor controlling isoseismal patterns, was quantitatively evaluated. Incorporating this regional variation into the model results in the prediction that in terms of energy released, the San Francisco earthquake of 1906 was 50 times as large as Owens Valley 1872 and more than 100 times larger than the Charleston 1886 and New Madrid 1811 earthquakes. All of these were probably of comparable "magnitude." Other relevant parameters are investigated. Analysis of probability of occurrence of major earthquakes in the Eastern United States suggests average annual return times of intensity X and IX of thousands of years at least. Presently unknown local conditions may lead to much greater probabilities at some localities, and the importance of developing procedures for determining regions of abnormally high risk is stressed.

● 3.1-9 Nazarov, A. G. *et al.*, **Quantitative determination of earthquake intensity**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 13, 5. (For a full bibliographic citation see Abstract No. 1.2–8.)

The evolution of modern earthquake-resistant construction has resulted in the necessity for devising stricter methods to evaluate the intensity of strong earthquakes as compared to the estimations made using the traditional earthquake intensity scale, which relies on qualitative data of macroseismic observations. To this end, it is suggested that the displacement vector of the earth as a function of time be regarded directly as the measure of earthquake intensity. Studies have been made to determine the characteristic accelerograms for estimating the seismic stability of buildings.

● 3.1-10 Fischer, J. A. and Chou, I.-H., **Procedures and confidence limits for earthquake hazard studies**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 155, 14. (For a full bibliographic citation see Abstract No. 1.2–8.)

Byerly has said, "the further we are from one earthquake the closer we are to the next." This truism is hardly reflected in one of the mathematical models used in today's analysis—the memoriless Poisson's distribution. The Poisson process, although mathematically simple, neglects the effects of the intervals between earthquakes. Thus, the authors suggest the use of a Weibull process as a mathematical analog to the seismological concept of the release of strain energy. This paper will provide the procedures and confidence limits for earthquake hazard studies.

● 3.1-11 Martemyanov, A. I. and Shirin, V. V., **On the estimation of the earthquake intensity using macroseismic observations of buildings with antiseismic amplification,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 10, 7. (For a full bibliographic citation see Abstract No. 1.2–8.)

For corresponding groups of buildings, the assessment of structural damage is done by means of building damage coefficients. Using the method of statistical interpretation, the authors find the dependence between the seismic intensity effect and the value of the reduced degree of damage in brick buildings with various seismic-resistant

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reinforcement. The expediency of the assessment of earthquake intensities by means of this method was confirmed by the 1966 Tashkent earthquake.

3.1-12 Napetvaridze, Sh. G. *et al.*, **Practical results in the solution of the inverse problem of the theory of structural earthquake resistance** (Nekotorye prakticheskie rezultaty resheniya obratnoi zadachi teorii seismostoikosti, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 67–75.

A technique is considered for calculating the parameters of ground motion at the base of a cantilever structure using instrumental data on vibrations at the upper levels of the structure and on the soil surface. Records of the San Fernando and Koyna earthquakes are used to demonstrate the influence of the angular frequency of the first mode on the peak acceleration, velocity and strain values in rock bases. Peak acceleration values are lowered by two-thirds if the method recommended is used in design.

3.2 Strong Motion Records, Interpretation, Spectra

● 3.2-1 Hanks, T. C., **Strong ground motion of the San Fernando, California, earthquake: Ground displacements,** *Bulletin of the Seismological Society of America,* **65**, *1*, Feb. 1975, 193–225.

Two hundred thirty-four components of ground displacement are the basis of an investigation of long-period strong ground motion in southern California arising from the San Fernando, California, earthquake. The displacement data are obtained from the double integration of strong-motion accelerograms via the base-line adjustment and filtering operations routinely performed in the series *Strong Motion Earthquake Accelerograms.* These procedures can recover long-period data from strong-motion accelerograms with considerable accuracy. Many-station comparisons of displacement data for which the station spacing is small compared to the wavelengths of interest reveal that uncertainties in displacement are less than 1 cm in the period range 5 to 8 sec, 1 to 2 cm at periods near 10 sec, and 2 to 4 cm in the period range 10 to 15 sec, for a data sensitivity of approximately 7.6 cm/g. For limited variations in epicentral distance (R) and source-station azimuth (ϕ), ground displacements show a strong coherence; for wider variations in R and ϕ, many of the observed variations in the displacement wave forms are easily attributable to well-understood seismological phenomena. Seismic moment, source dimension, radiation pattern, rupture propagation, the development of surface waves and their subsequent dispersion, and azimuthal variations in the gross geological structure all appear to have first-order significance in fashioning the gross amplitude and frequency content of the displacement wave forms and in explaining observed variations with R and ϕ. The essential simplicity of these displacement wave forms offers considerable optimism that long-period strong ground motion can be realistically synthesized with advance knowledge of the earthquake source parameters and gross geological structure.

● 3.2-2 Trifunac, M. D. and Brady, A. G., **On the correlation of seismoscope response with earthquake magnitude and Modified Mercalli intensity,** *Bulletin of the Seismological Society of America,* **65**, *2*, Apr. 1975, 307–321.

A quantitative measure of the Modified Mercalli Intensity Scale for earthquakes in the western United States has been developed by correlating the peak seismoscope relative displacement response, S_d, with the reported site intensity, I_{MM}. The data used in this study do not indicate an obvious type of dependence of S_d on local site conditions.

A method for computing the analog of the local earthquake magnitude, $M_{seismoscope}$, is presented for possible use in strong-motion seismology and for scaling earthquakes by close-in measurements, when other seismological instruments may go off scale.

● 3.2-3 Trifunac, M. D. and Brady, A. G., **On the correlation of peak acceleration of strong motion with earthquake magnitude, epicentral distance and site conditions,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 43–52.

Statistical analyses and correlations of peak accelerations with earthquake magnitude, epicentral distance and the geologic conditions of the recording sites are presented for 188 accelerograms recorded during 57 earthquakes. So far, this is the most complete data set describing strong earthquake ground motion in the Western United States during the period from 1933 to 1971.

It is shown that the peaks of strong-motion acceleration depend on earthquake magnitude only for small shocks. For large magnitude earthquakes this dependence appears to be lost, suggesting that the acceleration maxima recorded close to the source of energy release depend more on the dislocation amplitudes and the stress drop, rather than the overall "size" of an earthquake. It is shown that the attenuation of strong ground motion with distance can be approximated by the empirical attenuation law developed for the definition of Richter's local magnitude scale. The influence of geologic conditions is shown to be of minor importance for scaling peak accelerations.

3.2-4 Nathan, N. D. and MacKenzie, J. R., **Rotational components of earthquake motion,** *Canadian Journal of Civil Engineering,* **2**, *4*, Dec. 1975, 430–436.

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A complete record of torsional ground motion is generated from the two translational components of an earthquake record, following the ideas of Newmark. The approximate spectra developed by Newmark are generally confirmed. The assumptions and the limits of validity are discussed. Code provisions for this phenomenon are commented upon.

● 3.2-5 Resch, F. J. and Abel, R., **Spectral analysis using Fourier transform techniques,** *International Journal for Numerical Methods in Engineering,* **9,** *4,* 1975, 869-902.

The present study is intended as a guide for those who wish to undertake spectral analyses using discrete fast Fourier transforms. Points of particular difficulty in using Fourier transforms are derived in some detail. Experimental results are offered to illustrate the mathematical derivations. Finally the case of a signal with discontinuities along the time axis is discussed.

● 3.2-6 Adams, W. M., **First strong-motion instrumentation in Hawaii: With results from the earthquake of April 26, 1973,** *Bulletin of the Seismological Society of America,* **64,** *6,* Dec. 1974, 1909-1918.

On Apr. 26, 1973, an earthquake with a magnitude of 6 1/4 occurred at a depth of 40 km below Honomu (north of Hilo). Fortuitously, in the preceding February, one SMA-1 accelerograph and one Wilmot seismoscope were installed near Waikiki on the island of Oahu. Also, one SMA-1 accelerograph and three Wilmot seismoscopes were installed on the island of Hawaii. The records from these instruments provided the first strong-motion data for the state of Hawaii. The motion was dominantly horizontal. This finding explains the extensive damage to the Hilo area, reported to be about six million dollars.

● 3.2-7 Takada, S. and Komatsu, A., **Analysis of strong-motion accelerograms,** *Bulletin of the Disaster Prevention Research Institute,* 24, *Part 3,* Sept. 1974, 147-203.

In order to estimate the strain amplitudes occurring in underground structures subjected to earthquakes, data integrating techniques for strong-motion earthquake accelerograph records are investigated. Excellent base-line corrections and high-pass filtering methods for use with integrated velocity and displacement curves are discussed. From the results of numerical integration of 19 accelerograms, empirical formulas related to the maximum velocity amplitude and acceleration, etc., are proposed.

● 3.2-8 Singh, M. P., **Generation of seismic floor spectra,** *Journal of the Engineering Mechanics Division, ASCE,* **101,** *EM5,* Proc. Paper 11651, Oct. 1975, 593-607.

A simple method is presented for the direct generation of floor response spectra from a given ground response spectrum. A common method for generating floor spectra is to carry out a time-history analysis for a ground spectrum-consistent accelerogram. Unless an ensemble of such accelerograms is used, the response results cannot be relied upon; but the use of an ensemble of accelerograms is cumbersome and costly. A method that can directly use a prescribed spectrum is preferred. The proposed method is based on transfer characteristics of the structure for random excitation, and makes use of the structural frequencies, mode shapes and participation factors, and the prescribed spectrum to generate floor spectra. In the paper, the use of the proposed method is demonstrated by generating floor spectra of a building. The proposed method is simple and especially convenient for use on digital computers.

● 3.2-9 Rustanovich, D. N., **Surface ground motion in epicentral zones of strong earthquakes** (Kolebaniya poverkhnosti Zemli v epitsentralnykh zonakh silnykh zemletryasenii, in Russian), NAUKA Publishers, Moscow, 1974, 100.

Approximately 200 earthquake records obtained during the Ashkhabad (1948), Groznyi (1966), Tashkent (1966), Zangezour (1968), Borzhomi (1970), and Dagestan (1970) earthquakes are presented. Earthquake parameters and data on recording stations are tabulated. The volume is of special significance for the theory and practice of seismic microzoning and earthquake engineering.

The volume is published in accordance with a resolution of the Inter-departmental Council on Seismology and Earthquake Engineering of the Academy of Sciences of the U.S.S.R., adopted in 1971. A second volume, containing an analysis of instrumental data and seismological investigations of focal zones, is planned.

3.2-10 Demikhovskaya-Kulieva, E. M., **Ground motion spectra of earthquakes with epicenters in the south-eastern Caucasus** (Spektry kolebanii gruntov pri zemletryaseniyakh iz ochagov Yugo-Vostochno go Kavkaza, in Russian), *Izvestiya AN Azerbaidzhanskoi SSR, Seriya nauk o Zemle,* 2, 1974, 106-113.

Records of weak earthquakes with epicenters in the Shemakhin and Apsheron regions of Azerbaidzhan are analyzed. Spectral curves are constructed by averaging 10 to 20 earthquakes for various soils. The study indicates that the shape of the curves does not depend on source mechanisms. Sharp resonance is observed in the case of porous surface soil layers but not in the case of hard soils. Resonance can be expected in soil-structure systems for wavelengths between 40 and 300 m and soil layers 10 to 75 m deep.

● 3.2-11 Penzien, J. and Watabe, M., **Characteristics of 3-dimensional earthquake gound motions,** *International*

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Journal of Earthquake Engineering and Structural Dynamics, 3, *4*, Apr.–June 1975, 365–373.

An orthogonal set of principal axes is defined for earthquake ground motions along which the component variances have maximum, minimum and intermediate values and the covariances equal zero. Corresponding axes are defined which yield maximum values for the covariances. The orthogonal transformations involved are identical in form to those used in the transformation of stress. Examination of real accelerograms reveals that the major principal axis points in the general direction of the epicenter and that the minor principal axis is nearly vertical. It is concluded that artificially generated components of ground motion need not be correlated statistically provided they are directed along a set of principal axes.

● 3.2-12 Pletnev, K. G., Roman, A. A. and Shebalin, N. V., **Correlation between ground motion parameters and intensity from data of the 1970 Dagestan earthquake aftershocks** (Korrelatsiya mezhdu parametrami kolebanii i ballnostyu po dannym povtornykh tolchkov Dagestanskogo zemletryaseniya 1970 g., in Russian), *Byulleten po inzhenernoi seismologii*, *9*, 1975, 5–14.

Various methods for a precise calculation of intensity and a reduction of the dispersion of gound motion parameters are presented on the basis of instrumental recordings of the aftershocks of the 1970 Dagestan earthquake.

● 3.2-13 Papalashvili, V. G. and Aivazishvili, I. V., **On the relation between acceleration and magnitude in Georgia earthquake records** (O svyazakh velichin uskoreniya i ballnosti po zapisyam zemletryasenii v Gruzii, in Russian), *Byulleten po inzhenernoi seismologii*, *9*, 1975, 46–50.

An attempt to establish the relations between acceleration and magnitude from examples of earthquakes in the Georgian S.S.R. is made. The techniques of processing seismograms for this purpose are discussed.

● 3.2-14 Yartseva, I. S., **Results of generalization and analysis of strong earthquake data in the literature** (Nekotorye rezultaty obobshcheniya i analiza literaturnykh dannykh o silnykh zemletryaseniyakh, in Russian), *Byulleten po inzhenernoi seismologii*, *9*, 1975, 58–71.

Results obtained from a study of strong earthquake data found in the literature are presented. A primary classification of acceleration records according to earthquake parameters and, where possible, seismological conditions at the recording sites is given. Qualitative relations between various earthquake parameters are found by means of an analysis of source parameters and geological conditions at the recording sites, using a collection of macroseismic data.

Diagrams, describing the variations in maximal velocity and ground motion intensity during strong earthquakes with epicentral distance and earthquake magnitude, are constructed.

● 3.2-15 Rautian, T. G., **Development of accelerograms of strong earthquakes from broad-band recordings of weak ones** (Postroenie seismogramm silnykh zemletryasenii po shirokopolosnym zapisyam slabykh, in Russian), *Byulleten po inzhenernoi seismologii*, *9*, 1975, 85–98.

The problem of predicting strong earthquake ground motion using recordings of weak earthquakes with the same source obtained at the same location is considered.

● 3.2-16 Kameda, H., **Evolutionary spectra of seismogram by multifilter**, *Journal of the Engineering Mechanics Division, ASCE*, **101**, *EM6*, Proc. Paper 11805, Dec. 1975, 787–801.

The multifilter technique is applied to calculation of the evolutionary power spectra of strong-motion seismograms. Formulation of the evolutionary power spectrum is made in terms of the total energy of the filter output, the result of which is applied to accelerograms recorded in the United States and Japan. On the basis of numerical results, the acceptable range of the filter damping factor is found to be 0.05 - 0.2. It is shown that simulated accelerograms based on the evolutionary power spectra obtained in this study maintain quite well the nonstationarity of the original accelerograms both in intensity and spectral characteristics.

● 3.2-17 Trifunac, M. D. and Brady, A. G., **On the correlation of seismic intensity scales with the peaks of recorded strong ground motion**, *Bulletin of the Seismological Society of America*, **65**, *1*, Feb. 1975, 139–162.

Correlations of the recorded peak acceleration, velocity and displacement, and the modified Mercalli intensity have been carried out for 57 earthquakes and 187 strong-motion accelerograms recorded in the Western United States. Correlations of peak acceleration with intensity, characterized by the data scatter exceeding one order of magnitude, have led to average peak accelerations which are higher than those reported by a majority of previous investigators. New correlations, also characterized by scatter of data of about one order of magnitude, have been presented for peak velocities and displacements of strong ground motion versus modified Mercalli intensity.

Grouping of all recorded data according to the geology underlying the strong-motion accelerograph stations was carried out and permitted a study of the possible effects that local geology might have on the peaks of strong-motion acceleration, velocity, and displacement. Results of this analysis are as follows: (1) For ground shaking of a

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particular modified Mercalli intensity, average peak acceleration recorded on hard rock is higher by a factor less than about two than the average peak acceleration recorded on alluvium; (2) the effect of local geology on the average peak velocity leads to marginally higher peak values on alluvium; and (3) the peak ground displacements are larger, by a factor less than two, when recorded on alluvium rather than on hard rock.

● 3.2-18 Trifunac, M. D. and Brady, A. G., **A study on the duration of strong earthquake ground motion**, *Bulletin of the Seismological Society of America*, 65, 3, June 1975, 581-626.

A simple definition of the duration of strong earthquake ground motion based on the mean-square integral of motion has been presented. It is closely related to that part of the strong motion which contributes significantly to the seismic energy as recorded at a point and to the related spectral amplitudes. Correlations have been established between the duration of strong-motion acceleration, velocity, and displacement and modified Mercalli intensity, earthquake magnitude, the type of recording site geology, and epicentral distance. Simple relations have been presented that predict the average trend of the duration and other related parameters as a function of modified Mercalli intensity, earthquake magnitude, site geology and epicentral distance.

● 3.2-19 Hays, W. W., **A note on the duration of earthquake and nuclear-explosion ground motions**, *Bulletin of the Seismological Society of America*, 65, 4, Aug. 1975, 875-883.

The duration of ground acceleration, an important engineering seismology parameter, was determined for a subset of nuclear explosion and earthquake accelerograms. The nuclear-explosion, ground-motion data sample consisted of accelerograms derived from velocity recordings of high-yield events, MILROW and CANNIKIN, which have been assigned surface-wave magnitudes of 5.3 and 5.7, respectively. The earthquake-data sample consisted primarily of the Richter magnitude 6.6 San Fernando earthquake accelerograms. The criterion used to define duration of ground acceleration was the amount of time that the absolute acceleration is ≥ 5 per cent g, an approximate index of the strong phase of ground shaking. On the basis of this criterion and the data subset used, the duration of earthquake ground acceleration differs from that of nuclear explosions. The difference, which is not as great as has generally been thought in the past, is small inside 20 km. Earthquake durations are greater beyond 20 km. The scatter in the duration data was analyzed and found to be sensitive to local site amplification phenomena. These preliminary conclusions need to be validated by further research.

● 3.2-20 Holzapfel, A., Arias, A. and Saragoni, G. R., **An approximated expression for the mean square acceleration of earthquake ground motions**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 289-296.

A beta function approximation for the mean square acceleration of earthquake ground motions is considered. The expression is obtained under the assumption that the seismic wave path between the earthquake source and the accelerometer site can be represented by a moderately large number of linear and time invariant filters acting in cascade. A method to estimate the intensity parameter and the two shape parameter constants is developed and applied to 30 earthquake records obtained from the West Coast of the U.S. and from Latin America.

Comparison between theoretical results and estimates from real earthquakes shows that the function is a good approximation of the mean square acceleration of earthquake processes. However, the approximation fails in the case of earthquake processes of very short duration, recorded at short epicentral distances and on rocky soils.

The beta function gives practically the same curves for the mean square acceleration as the chi-square limiting expression derived by Saragoni.

● 3.2-21 Joannon, J. G., Arias, A. and Saragoni, G. R., **The variation of the frequency content of earthquake accelerograms**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 4, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

A theoretical method is presented to estimate the time variation of the predominant frequency of earthquake acceleration and velocity records. This method uses the ratios between the mean square functions of velocity, acceleration and the derivative of acceleration. It has been applied to 32 earthquake accelerograms from the U.S.A., Mexico, Peru and Chile with satisfactory results. The determined functions for the predominant frequency of acceleration records are in agreement with functions estimated by other authors using a different method. This time variation is characterized by a chi-square decay trend, which is particularly significant in some 1971 San Fernando earthquake records.

● 3.2-22 Büyükaşikoglu, S., **Analysis of seismic waves in the period range of 1 to 10 seconds**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 15, 8. (For a full bibliographic citation see Abstract No. 1.2-8.)

The seismograms of different earthquakes in the magnitude range of M=4.7 to 6.4, recorded with a velocity-type seismograph, are investigated. It is determined that

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the average velocity spectrum of earthquakes with magnitude greater than M=5.5 recorded at a particular site is considerably flat in the period range of 1 to 10 sec.

● 3.2-23 Allam, A., **Relation between long-period microtremors and the underground structure,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 25, 10. (For a full bibliographic citation see Abstract No. 1.2-8.)

Long-period microtremor recordings were carried out in the Tokyo metropolitan area and in Saitama Prefecture along a line connecting Sunamachi and Kasukabe. A horizontal seismometer having a natural period of 5 sec was used in the recordings. The power spectra of microtremors were computed and it was found that their predominant frequencies differed at various sites. By calculating the 95% confidence limits of the regression line of the predominant frequencies of the power spectra of the microtremors, it was found that the predominant frequency increases towards Kasukabe. Thus, the bedrock is shallower at Kasukabe than at Sunamachi. The trend of this result is in favor of the seismic prospecting data available for two different sites.

● 3.2-24 Capecchi, A. and Conti, G., **Longitudinal waves in sand specimens and stress-strain relationships,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 29, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

During the past few years, the authors have been conducting experimental research to determine longitudinal wave propagation velocities in continuous media specimens. The results have permitted the development of new methodologies for continuous materials in the elastic field. In this paper, the methodologies are extended to granular media, enabling one to determine easily the bar and bulk velocities in dry sand specimens.

In order to clarify the connection between these velocities and the stress-strain relationships in the granular media, it was deemed necessary to measure the moduli and the Poisson ratio of the specimens by quasistatic tests. An aedometer was therefore developed to measure the thrust exerted by the specimens on the wall. The behavior of the sand specimens is discussed.

3.2-25 Skorik, L. A. and Shervud, L. Ya., **Amplitude and frequency characteristics of earthquakes near the Chirkei Hydroelectric Power Plant** (Amplitudno-chastotnye kharakteristiki zemletryasenii v raione Chirkeiskoi GES, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki,* 87, 1973, 45-49.

The first results of the analysis of seismometric data obtained in the region of the Chirkei Hydroelectric Power Plant are presented. The computer analysis uses the program SPECTRUM, developed by the Earth Physics Inst. of the Academy of Sciences of the U.S.S.R. Amplitude and frequency characteristics of seismic vibrations in the canyon walls are obtained. Variations in those characteristics are traced as the height of the observation point changes.

● 3.2-26 Büyükaşikoglu, S. and Shima, E., **Spectra of seismic waves in the period range from 1 to 10 seconds,** *Bulletin of the International Institute of Seismology and Earthquake Engineering,* 13, 1975, 23-44.

Long period seismic waves were recorded at two sites near Tokyo. A velocity-type seismometer having a natural period of 5 sec was used. The earthquake records in the period range from 1 to 10 sec were Fourier analyzed. The magnitudes of these earthquakes were between 4.3 and 6.4. The average velocity spectrum of the earthquakes with $M \geq 5.5$ was found to be considerably flat in the frequency range from 0.2 to 1.0 Hz; this agrees with Aki's revised model B.

● 3.2-27 Allam, A., Yanagisawa, M. and Shima, E., **Spectra of long period microtremors with special application to the characteristics of seismic waves,** *Bulletin of the International Institute of Seismology and Earthquake Engineering,* 13, 1975, 87-100.

A horizontal seismometer having a natural frequency of 0.2 Hz was used in recording long-period microtremors in Tokyo and in Saitama Prefecture, along a line connecting Sunamachi and Kasukabe City. It was found that the predominant frequencies of their power spectra vary at different sites. By calculating the 95% confidence limits of the regression line of the predominant frequencies of the microtremor power spectra, it was found that the predominant frequencies increase towards Kasukabe City. Thus, if seismic wave velocities of the underlying layers are the same for all the sites, then the thickness of these layers decreases toward Kasukabe City. The underground structures of these same sites were later clarified by the Yumenoshima explosion. These were used as models for the computation of the spectral response of the ground and the dispersion curves of both Love and Rayleigh waves. It was found that the predominant frequencies of the power spectra coincide with the frequencies of the minimum group velocities of the fundamental modes of Rayleigh waves. However, the predominant frequencies of the spectral responses and the frequencies of the minimum group velocities of the fundamental modes of Love waves do not coincide with the predominant frequencies of the power spectra. The power spectra of microtremors having lower frequencies were examined using a 0.1 Hz seismometer placed in the basement of the Earthquake Research Inst. of the Univ. of Tokyo. This site is assumed to have the same underground structure as that of the southern part of the explored area. It was found that the predominant fre-

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quency of these microtremors coincided, at a lower frequency, with that of the minimum group velocity of the fundamental modes of Love waves.

● 3.2-28 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. I, Part T,** *EERL 73-25*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Jan. 1975, 223.

This issue contains uncorrected records from the El Centro, California, site in the basement of the Imperial Valley Irrigation District substation, from 1938 to 1966, including nine groups of aftershocks of the May 18, 1940, Imperial Valley earthquake.

● 3.2-29 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. I, Part U,** *EERL 73-26*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Feb. 1975, 296.

This issue contains uncorrected California records from Ferndale, Santa Barbara, Hollister, Tehachapi, San Jose, and Taft, together with uncorrected records from Helena, Montana, and Seattle, Washington, during the years 1934 to 1967. Further records from some of these sites have appeared in other parts of the series.

● 3.2-30 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. I, Part V,** *EERL 73-27*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Mar. 1975, 238.

This issue contains uncorrected California records from the Los Angeles and Long Beach areas, San Luis Obispo, various buildings in the San Francisco Bay area, Port Hueneme, Eureka, Castaic, and Sacramento during the years 1933 to 1967. Further records from some of these sites have appeared in other parts of the series.

● 3.2-31 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. I, Part W,** *EERL 73-28*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Mar. 1975, 225.

This issue contains data from the Lytle Creek, California, earthquake of Sept. 12, 1970, and includes three uncorrected records each from the buildings at 945 Tiverton and 120 N. Robertson in Los Angeles; two uncorrected records each from the Hollywood Storage Building in Los Angeles, the JPL Building and the Millikan Library in Pasadena, and the Cedar Springs CWR site; and single uncorrected records from Wrightwood, Devil's Canyon and the Hall of Records in San Bernardino, Colton, Puddingstone Dam in San Dimas, Santa Anita Dam in Arcadia, and the Old Ridge Route in Castaic.

● 3.2-32 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. I, Part X,** *EERL 73-29*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Apr. 1975, 127.

This issue contains data from the Lytle Creek, California, earthquake of Sept. 12, 1970, and includes three uncorrected records each from the buildings at 1640 Marengo, the Dept. of Water and Power, 808 S. Olive, and 646 S. Olive in Los Angeles; two uncorrected records from the building at 445 Figueroa in Los Angeles; and a single uncorrected record from Fire Station No. 78, a CWR site at Lake Hughes, No. 1.

● 3.2-33 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. I, Part Y,** *EERL 73-30*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Apr. 1975, 212. (NTIS Accession No. PB 242 946)

This issue is the final part of a series initiated in July 1969 and contains data from the Borrego Mountain, California, earthquake of Apr. 8, 1968, including two uncorrected records each from the JPL Building in Pasadena and the Hollywood Storage Building in Los Angeles and single uncorrected records from Colton, Santa Ana, Terminal Island in Long Beach, the Millikan Library and Athenaeum at Caltech in Pasadena, the Edison Building at 601 W. 5th St. and the Subway Terminal, both in Los Angeles, and Vernon. Other uncorrected records from El Centro, San Diego and San Onofre were included in Parts A and B.

● 3.2-34 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. II, Parts O and P,** *EERL 74-55*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, June 1974, 302. (NTIS Accession No. PB 239 586/AS)

This report continues from Part N the corrected accelerogram data of Vol. II for accelerograms II0198 to II0201, II0204 to II0208, II0210, II0213, IIP214 to IIP223, IIP231 and IIP232. The corrected data of this volume correspond to the uncorrected data from the earthquakes listed in Vol. I, Parts O and P.

● 3.2-35 **Strong motion earthquake accelerograms, digitized and plotted data, Vol. II, Parts Q and R,** *EERL 74-56*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Sept. 1974, 205. (NTIS Accession No. PB 239 587/AS)

This report continues from Part P the corrected accelerogram data of Vol. II for accelerograms IIQ233 to IIQ243 and IIR244 to IIR254. The corrected data of this volume correspond to the uncorrected data from the earthquakes listed in Vol. I, Parts Q and R.

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● **3.2-36 Strong motion earthquake accelerograms, digitized and plotted data, Vol. II, Part T,** *EERL 75-50,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Feb. 1975, 259.

This report continues from Part S the corrected accelerogram data of Vol. II for accelerograms IIT247 through IIT293. The corrected data of this volume correspond to the uncorrected data from the earthquakes listed in Vol. I, Part T.

● **3.2-37 Strong motion earthquake accelerograms, digitized and plotted data, Vol. II, Part U,** *EERL 75-51,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Feb. 1975, 298. (NTIS Accession No. PB 242 949)

This report continues from Part T the corrected accelerogram data of Vol. II for accelerograms IIU294 through IIU313. The corrected data of this volume correspond to the uncorrected data from the earthquakes listed in Vol. I, Part U.

● **3.2-38 Strong motion earthquake accelerograms, digitized and plotted data, Vol. II, Part V,** *EERL 75-52,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Mar. 1975, 262. (NTIS Accession No. PB 242 948)

This report continues from Part U the corrected accelerogram data of Vol. II for accelerograms IIV314 through IIV333. The corrected data of this volume correspond to the uncorrected data from the earthquakes listed in Vol. I, Part V.

● **3.2-39 Strong motion earthquake accelerograms, digitized and plotted data, Vol. II, Parts W and Y,** *EERL 75-53,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Apr. 1975, 256.

This report continues from Part V the corrected accelerogram data of Vol. II for accelerograms IIW334 to IIW336, IIW338, IIW339, IIW342 to IIW345 and IIY370 to IIY381. The corrected data of this volume correspond to the uncorrected data from the earthquakes listed in Vol. I, Parts W and Y.

● **3.2-40 Analyses of strong motion earthquake accelerograms, Vol. III, Part G,** *EERL 73-85,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Dec. 1973, 124. (NTIS Accession No. PB 231 223/AS)

This report continues from Part F the response spectra of Vol. III derived from earthquake accelerograms IIG106 through IIG114. The spectrum plots of this volume correspond to the corrected data of Vol. II, Part G and to the uncorrected data of Vol. I, Part G.

● **3.2-41 Analyses of strong motion earthquake accelerograms, Vol. III, Part S,** *EERL 74-86,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Oct. 1974, 246.

This report continues from Part R the response spectra of Vol. III derived from earthquake accelerograms IIS255 through IIS273. The spectrum plots of this volume correspond to the corrected data of Vol. II, Part S and to the uncorrected data of Vol. I, Part S.

● **3.2-42 Analyses of strong motion earthquake accelerograms, Vol. III, Part T,** *EERL 75-80,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Feb. 1975, 260.

This report continues from Part S the response spectra of Vol. III derived from earthquake accelerograms IIT274 through IIT293. The spectrum plots of this volume correspond to the corrected data of Vol. II, Part T and to the uncorrected data of Vol. I, Part T.

● **3.2-43 Analyses of strong motion earthquake accelerograms, Vol. III, Part U,** *EERL 75-81,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Feb. 1975, 262. (NTIS Accession No. PB 242 950)

This report continues from Part T the response spectra of Vol. III derived from earthquake accelerograms IIU294 through IIU313. The spectrum plots of this volume correspond to the corrected data of Vol. II, Part U and to the uncorrected data of Vol. I, Part U.

● **3.2-44 Analyses of strong motion earthquake accelerograms, Vol. III, Part V,** *EERL 75-82,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Mar. 1975, 262. (NTIS Accession No. PB 242 951)

This report continues from Part U the response spectra of Vol. III derived from earthquake accelerograms IIV314 through IIV333. The spectrum plots of this volume correspond to the corrected data of Vol. II, Part V and to the uncorrected data of Vol. I, Part V.

● **3.2-45 Analyses of strong motion earthquake accelerograms, Vol. III, Parts W and Y,** *EERL 75-83,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Apr. 1975, 275.

This report continues from Part V the response spectra of Vol. III derived from earthquake accelerograms IIW334 to IIW336, IIW338, IIW339, IIW342 to IIW345

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and IIY370 to IIY381. The spectrum plots of this volume correspond to the corrected data of Vol. II, Parts W and Y and to the uncorrected data of Vol. I, Parts W and Y.

● 3.2-46 **Analyses of strong motion earthquake accelerograms, Vol. IV, Parts Q, R and S,** *EERL 74-104*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Oct. 1974, 276.

This report continues from Part P the Fourier amplitude spectra of Vol. IV derived from accelerograms IIQ233 to IIQ243, IIR244 to IIR254 and IIS255 to IIS273. The records analyzed in this volume match the corrected data of Vol. II, Parts Q, R and S and the uncorrected data of Vol. I, Parts Q, R and S.

● 3.2-47 **Analyses of strong motion earthquake accelerograms, Vol. IV, Parts T and U,** *EERL 75-100*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Mar. 1975, 264.

This report continues from Part S the Fourier amplitude spectra of Vol. IV derived from accelerograms IIT274 to IIT293 and IIU294 to IIU313. The records analyzed in this volume match the corrected data of Vol. II, Parts T and U and the uncorrected data of Vol. I, Parts T and U.

● 3.2-48 **Analyses of strong motion earthquake accelerograms, Vol. IV, Parts V, W and Y,** *EERL 75-101*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Apr. 1975, 273.

This report continues from Part U the Fourier amplitude spectra of Vol. IV derived from accelerograms IIV294 to IIV333, IIW334 to IIW336, IIW338, IIW339, IIW342 to IIW345 and IIY370 to IIY381. The records analyzed in this volume match the corrected data of Vol. II, Parts V, W and Y and the uncorrected data of Vol. I, Parts V, W and Y.

● 3.2-49 Wang, W. Y.-L., **Structural instability during earthquakes and accelerogram simplification,** *UMEE 75R2*, Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Apr. 1975, 291.

A simple method for predicting structural response is possible if the complicated earthquake accelerogram can be simplified. In this study, a simple model accelerogram takes the form of four alternating rectangular pulses whose values are determined by a minimization process.

The equations of motion for structures are established. Both a circular and a linear path for structural oscillation are considered, and it is found that these two paths are identical for small angular oscillations. The equation of motion includes the gravity effect because it may lead to the collapse of the structure. Pertinent parameters shown in the equation of motion are given values so that the resulting structures will be realistic.

Three accelerogram records of El Centro, Taft and Pacoima Dam sites are used to investigate structural response to strong ground motions. The response of structures is examined up to the collapse. The method for constructing the four-pulse model accelerogram is developed, and structural response due to the model accelerograms is presented. Displacement spectra of structures in both the elastic and the inelastic ranges due to these model accelerograms are similar to those due to the real accelerograms of El Centro, Taft and Pacoima Dam. Because of this capability of the model accelerogram, it also is constructed for an elastic design spectrum. The inelastic displacement spectra from such a model accelerogram are closer to those from real accelerograms than the ones predicted by an existing method.

3.2-50 Nakamura, M., Taga, N. and Matsuoka, O., **Aseismic problems of the structures subjected to multi-input seismic waves—Part 1: Input ground motions** (in Japanese), *Transactions of the Architectural Institute of Japan*, 232, June 1975, 51-61.

Spectral analysis and time history analysis are two methods used to subject structures to multi-input seismic waves. In this paper, the data needed for these analyses are discussed.

For spectral analysis, the theoretical correlation functions and spectral density functions between acceleration, velocity and displacement are obtained for three types of cases. These are (a) the same seismic waves, (b) seismic waves which have the same wave and time lag and (c) seismic waves which only have different Fourier amplitude spectra. From mean values of several acceleration power spectral density functions, one equation is obtained; and mean square power and cross-power spectral density functions are obtained.

For time history analysis, two methods are used: (a) the Fourier transform method and (b) simulation of seismographic records. The lower frequency part of the Fourier amplitude spectra can be cut off using the Fourier transform method. The relations between the maximum values of acceleration, velocity and displacement are given with the cutoff frequency. The best result is given when the cutoff frequency equals 1.0. The second method uses a filter to digitally simulate the movement of a simple pendulum. Velocity is obtained by the filter when the period is long and displacement is obtained when the period and the damping coefficient are 2.0 sec and 0.8, respectively, and when the amplification factor of displacement equals 2.7.

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3.3 Artificial and Simulated Earthquake Records

● 3.3-1 Duke, C. M. and Mal, A. K., **A model for analysis of body and surface waves in strong ground motion,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 17–24.

A new analytical model is described for the analysis of strong earthquake ground motion. The main feature of the model is the incorporation of transfer functions, based on exploration data, for surface waves as well as body waves. With these transfer functions, it is possible to compute the body wave and surface wave components of the motion recorded at one or more stations. The procedure can be extended to obtain improved representations of the transfer functions by making use of the body and surface parts of the instrumental data.

The model requires much improvement for analysis as well as data interpretation. Nevertheless, the technique, in its present form, should be useful for engineering analyses. All nonlinear effects except those at the source are ignored in the present phase of the research.

3.3-2 Suvilova, A. V., **Modeling strong-motion earthquake records in earthquake-resistant design** (Modelirovanie zapisi silnogo zemletryaseniya dlya rascheta seismostoikosti, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94,* 1974, 39–45.

Initial data for modeling earthquake records are analyzed. A system of computer programs is presented with a view to constructing flexible models of earthquake records. Such models may be used to evaluate seismic risk for various structures in cases of incomplete or approximate data on seismic parameters.

● 3.3-3 Nersesov, I. L., Rautian, T. G. and Khalturin, V. I., **Synthetic seismograms of strong earthquakes and seismic hazard evaluation** (Sinteticheskie seismogrammy silnykh zemletryasenii i otsenka seismicheskoi opasnosti, in Russian), *Seismostoikost plotin, 3,* 1975, 8–22.

A framework for constructing synthetic seismograms is presented. The method involves a study of the local features of seismic wave generation and propagation using a statistical evaluation of records of small earthquakes in the region and an extrapolation of these data to strong earthquakes.

● 3.3-4 Pavlova, I. N. *et al.*, **On choice of earthquake data for calculation of seismic response of hydraulic structures** (O podbore seismicheskikh zapisei dlya rascheta gidrotekhnicheskikh sooruzhenii na seismicheskie vozdeistriya, in Russian), *Byulleten po inzhenernoi seismologii, 9,* 1975, 72–75.

A method of developing simulated earthquake records in various seismic areas using earthquake records obtained in place or at remote sites is presented.

● 3.3-5 Karapetian, B. K., Karapetian, N. K. and Mekhitarian, L. A., **Modelling of seismic action by explosions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 12, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Data obtained in studying the propagation of explosion-generated seismic waves in bedrock are presented. The purpose of this investigation has been to determine the methods for regulating the explosion procedures in modelling seismic action developed during an earthquake. It has been established that seismic action can be modelled by inducing short-spaced successive explosions which produce ground motion quite similar to that created during an earthquake. This similarity is achieved by changing the basic parameters of seismo-explosive vibration, viz., prolonging the period and duration of vibration as well as reducing its distance damping.

3.4 Seismic Zoning

3.4-1 Bune, V. I. *et al.*, **Successes in and expectations from the seismic zoning of the USSR,** *Physics of the Solid Earth, 10,* Oct. 1974, 668–672.

The basic stages in the development of the investigation of seismic zoning of the U.S.S.R are described.

● 3.4-2 Liu, S. C. and De Capua, N. J., **Microzonation of Rocky Mountain states,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 128–135.

Results are presented of the microzonation studies of the Rocky Mountain states, next to California and Nevada, one of the most active seismic areas in the nation. The area studied covers most of the territory between 109°W and 114°W longitude, an area which has had considerable seismicity. The designation of a large portion of this area as zone 3, the highest risk zone on the Uniform Building Code map, has caused controversies among engineering professionals who do not consider the area to be as highly seismic as California. This study attempts to lessen such controversies and to present a clearer picture of the actual seismic risk of the area.

● 3.4-3 Borcherdt, R. D., **Studies for seismic zonation of the San Francisco Bay region: A brief summary,** *Proceedings of the U.S. National Conference on Earthquake*

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Engineering-1975, Earthquake Engineering Research Inst., Oakland, June 1975, 123–127.

Studies by 16 researchers in various earth science and engineering disciplines suggest that seismic zonation of the San Francisco Bay region is feasible using existing geological and geophysical knowledge. Basic tools derived for seismic zonation on a regional scale are (1) a map showing active faults, (2) data on attenuation of bedrock shaking with distance, (3) geologic data, (4) a map showing qualitative ground response, (5) a map showing potential inundation by tsunamis, (6) a map showing liquefaction potential, and (7) a map showing landslide susceptibility. A composite application of these seven basic tools along a profile for a postulated M ~ 6.5 earthquake on the San Andreas Fault illustrates a methodology for seismic zonation. Pending completion of this suggested seismic zonation, a predicted maximum intensity map prepared for the region delineates areas with potential earthquake problems; and the seven basic tools help identify the nature and possible severity of the problems in the various areas.

3.4-4 Vakhtanova, A. N., **On the use of various indicators of mechanical properties of rocks in problems of seismic microzoning** (Ob ispolsovanii nekotorykh pokazatelei mekhanicheskikh svoistv porod dlya resheniya zadach seismicheskogo mikroraionirovaniya, in Russian), *Izvestiya Akademii Nauk Turkmenskoi SSR*, 5, 1974, 53–56.

In contrast to existing methods of calculating the effects of porosity, moisture content and shear resistance of soils on seismic intensity amplification, the technique presented uses information regarding the character of limit equilibrium in the rock subjected to seismic excitation. The initial data include the internal friction angle and the angle of inclination of rock layers, as well as the incidence angle of seismic excitation. The output information is presented in terms of the seismic resistance coefficient whose value is over 0.65 for an area with seismicity 8, between 0.40 and 0.65 for seismicity 9 and under 0.4 for seismicity 10. The technique presented was employed in the region of the Keshenyn-Vairskaya hills in Turkmenistan.

● 3.4-5 Kogan, L. A., Nechaev, V. A. and Romanov, O. A., **Seismic microzoning in Tadzhikistan** (Seismicheskoe mikroraionirovanie v Tadzhikistane, in Russian), DONISH Publishers, Dushanbe, 1974, 380.

A systematic account of seismic microzoning in Tadzhikistan from 1937 to the present is given for the first time. Results of investigations in seismic hazard evaluation in the major cities of the republic (Dushanbe, Leninabad, and Regar) are presented. New seismic hazard evaluation methods based on a synthesis of geological and statistical techniques are discussed.

● 3.4-6 Chouhan, R. K. S. and Khan, A. A., **Seismic zoning of Bangla Desh**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 451–458.

During a comprehensive analysis of seismic activity, the eastern part of Bangladesh was found to be very seismically active. The regularities of earthquake occurrence in Bangladesh are determined in connection with movements and deformations of the area. Taking into account the local geology, the authors use data on the distribution, frequency of occurrence and intensities of earthquakes to zone the area.

● 3.4-7 Murphy, J. R. and Hewlett, R. A., **Analysis of seismic response in the city of Las Vegas, Nevada: A preliminary microzonation**, *Bulletin of the Seismological Society of America*, **65**, *6*, Dec. 1975, 1575–1597.

Ground motion data recorded at 26 different locations in Las Vegas from six underground nuclear tests have been used to perform a preliminary microzonation of the city. The microzonation results are presented in the form of contour maps of the average observed seismic response throughout the city in 12 different frequency bands covering the period range from 0.16 to 6.0 sec. These data indicate that variations in long-period seismic response of as much as an order of magnitude can be expected at sites only a few kilometers apart in the city. Simple models of surface-wave propagation in the surface layer of alluvium of variable thickness can account for much of the observed variability. However, it appears that surface waves reflected back from the valley boundaries at the base of the surrounding mountain ranges also have a significant effect on the measured response.

3.4-8 Kats, A. Z., **On the present state and prospects of seismic microzoning investigations** (O sostoyanii i perspektivakh issledovanii po seismicheskomu mikroraionirovaniyu, in Russian), *Byulletin po inzhenernoi seismologii*, *8*, 1973, 10–12.

Various aspects of problems in seismic microzoning are considered. The advantages and shortcomings of several methods are pointed out, and the prospects for seismic microzoning investigations are discussed.

3.4-9 Antonenko, E. M., Proshunina, S. A. and Atrushkevich, P. A., **Problems in the methodology of seismic microzoning** (Voprosy razrabotki metodiki seismicheskogo mikroraionirovaniya, in Russian), *Informatsionnyi sbornik nauchno-issledovatelskikh rabot instituta geologicheskikh nauk AN KazSSR, 1972*, NAUKA, Alma-Ata, 1973, 105–108.

The methodology of seismic microzoning in the Dushanbe region is discussed. Spectral composition and

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propagation of microtremors in various soils were studied. Observations were carried out in the Alma-Ata region in order to locate fault zones, to give a quantitative estimate of vertical displacements in densely populated areas, and to refine existing seismic microzoning maps of the region.

3.4-10 Pavlov, O. V. *et al.*, **Use of explosions for seismic microzoning in permafrost soils** (Opyt primeneniya vzryvov pri seismicheskom mikroraionirovanii na vechnomerzlykh gruntakh, in Russian), *Byulletin po inzhenernoi seismologii, 8,* 1973, 31–38.

The possibility of using explosions in seismic microzoning in permafrost conditions is demonstrated. Amplitude and frequency spectra obtained from explosions and earthquakes are compared with spectra calculated analytically. A seismic microzoning technique based on acoustic stiffness and explosions is presented.

3.4-11 Krasnikov, N. D., **Problems of seismic microzoning near hydroelectric power plants** (Nekotorye voprosy seismomikroraionirovaniya territorii gidrouzlov, in Russian), *Byulletin po inzhenernoi seismologii, 8,* 1973, 16–24.

Existing methods for seismic microzoning near hydroelectric power plants are analyzed. Individual properties of plant design must be taken into account in seismic microzoning. Factual data related to this question are obtained using specific examples. The complexity of the problem is pointed out and paths toward a solution are given.

● 3.4-12 Shah, H. C. *et al.*, **A study of seismic risk for Nicaragua (Part I)**, *11,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Jan. 1975, 318.

The geological settings for Nicaragua in general and the Managua area in particular are presented. The data base for past seismic events was studied extensively. Limitations of the data and approximations are discussed. Seismic recurrence for ten line sources and three area sources was developed. Based on the assumption of the Poisson occurrence of seismic events, probabilities of exceeding different magnitude levels as functions of time for different regions were derived.

Iso-acceleration maps for the country were constructed using Esteva's attenuation relationship. Eleven cities in Nicaragua were considered in this mapping process. Cumulative distribution functions of peak ground accelerations for 20 and 50 years were established. This is shown to be one way of presenting seismic risk for Nicaragua. Based on iso-acceleration maps, acceleration zone graphs (AZG) were developed for the eleven cities. A method of determining load levels for consistent risk for the whole country is discussed and suggested. It is proposed that charts such as AZG be used for seismic zoning of Nicaragua.

Another parameter, the MMI scale, is presented in a probabilistic sense. Based on damage data in the U.S.A., a method of determining insurance risk is presented. Ground acceleration values from AZG are employed to set the level of the design spectra for structural damage prevention and condemnation control. A design methodology is proposed based on ultimate strength and loads resulting from the above inelastic design spectra.

● 3.4-13 Kiremidjian, A. S. and Shah, H. C., **Seismic hazard mapping of California**, *21,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Nov. 1975, 85.

The objective of this study is to develop a seismic hazard map for the State of California. Such a map can be used for zoning purposes which in turn can be incorporated in building code formulations for design.

A probabilistic Poisson model is used for the development of the hazard map. Peak ground acceleration is used as a measure of the seismic hazard. In addition to the iso-acceleration map developed for the entire state, the cumulative distribution functions for seven cities in the state also are computed. From them, acceleration zone graphs, which can be useful in design, are obtained.

Actual application of the results to design practices are not developed in this report. There are, however, a few examples on the subject illustrating the method for obtaining the peak ground acceleration for a given type of structure as a function of its economic life and return period.

3.5 Influence of Geology and Soils on Ground Motion

3.5-1 Skovitin, A. I. and Kiryanov, M. S., **Results of measuring ground motion on slopes near structures** (Rezultaty izmerenii kolebanii gruntov na sklonakh vblizi sooruzhenii, in Russian), *Elementy metodiki seismicheskogo mikroraionirovaniya,* Shtiintsa Publishers, Kishinev, 1974, 45–50.

Ground motion records obtained from nine large explosions on slopes covered with fill or rocky soil and sand at epicentral distances of 0.6 to 2 km are compared. Seismological evidence indicates a twofold increase in intensity in porous soils and on sites with increased soil layer thickness.

● 3.5-2 Ershov, I. A. *et al.*, **Comparison of ground motion of varying intensity recorded in silty soil layers of varying thickness** (Sopostavlenie kolebanii raznoi intenzivnosti zapisannykh na lessakh raznoi moshchnosti, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 53–70.

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Data collected during field investigations in the Dushanbe region are analyzed. Weak earthquakes were simultaneously registered in gravel and loess soil layers with thicknesses between 12 m and 60 m. Microtremors were also observed. Frequency characteristics of soils at the observation points were determined. On the whole, the dominant frequencies of microtremors agree well with the resonant frequencies from the dynamic response characteristics of the soils. The ratio of maximal amplitudes in loess and gravel remains constant for weak earthquakes. In case of resonance the use of the ratio of maximal ground motion velocities is preferable.

● 3.5-3 Wong, H. L. and Jennings, P. C., **Effects of canyon topography on strong ground motion**, *Bulletin of the Seismological Society of America*, 65, 5, Oct. 1975, 1239–1257.

The two-dimensional scattering and diffraction of *SH* waves of arbitrary angle of incidence from irregular, canyon-shaped topography are formulated in terms of an integral equation. Taking advantage of the simple boundary conditions of *SH*-wave problems, the method of images is applied to reduce the integral equation to one with a finite integral, which can be solved readily by available numerical methods.

The method is first applied to the analytically solved case of a cylindrical canyon to verify its accuracy, and then to two idealized cross sections, based upon the Pacoima Canyon, to investigate the effects of topography in a more realistic case. The results of the harmonic analysis include wave amplification patterns and transfer functions for different wavelengths and for different angles of incidence. The study also includes analysis of transient motions. With the N76°W component of the Pacoima Dam accelerogram specified to occur at one point in the cross section, the effects of different angles of incidence upon the required input motion and upon the motion at several other points in the cross section were examined by calculating accelerograms and response spectra.

The effects of canyon-shaped topography are seen most prominently in the amplification patterns and transfer functions for harmonic response, wherein shielding and focusing can cause variations up to a factor of six for wavelengths comparable to, or shorter than, the canyon width. In the case of transient motions, the accelerograms at different points show significant differences, but not as large as seen in the harmonic analysis. The response spectra show the smallest differences; significant effects are confined to the higher frequencies.

● 3.5-4 Hamada, M. and Fujita, H., **Behaviors of the alluvial layers on the sloped bed rock during earthquakes**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 23, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Earthquake observations were made on ground where bedrock was sloped and the thickness of the surface layer changed gradually. The different dynamic characteristics between two points of the ground surface where the thicknesses of the surface layer were not the same were examined. The magnification ratios of the earthquake acceleration at the ground surface to that at the bedrock were obtained. The value of the vertical acceleration at the bedrock is discussed and compared with that of the horizontal acceleration. Numerical analyses were done by means of the finite element method and the lumped-mass method.

● 3.5-5 Finn, W. D. L., Tezcan, S. S. and Ipek, M., **A parametric study of soil amplification**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 34, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

Amplitude and frequency characteristics of the earthquake motion of a horizontally layered soil medium are studied, assuming an upward propagating shear wave input at the level of bedrock. Nonlinearity of the stress-strain relationship and also the strain dependence of the damping ratio are taken into account by an iterative approach.

Based on the results of numerous analyses, several conclusions are reached regarding the relative importance and influence of various geometric and physical soil parameters on soil amplification.

3.5-6 Dzhabauri, G. G., **Effects of seismic wave refraction, damping and multiple reflection on ground motion in two-layered soil strata** (Vliyanie na kolebaniya pochvi mnogokratnogo otrazheniya, perelomleniya i zatukhaniya seismicheskikh voln v dvukhsloinoi gruntovoi tolshche, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 170–177.

Analytic techniques are developed for calculating the effects of a multilayered porous stratum over an elastic halfspace on the transformation of seismic impulses arriving at the base of the stratum. A numerical method is presented allowing for 12 types of traveling seismic waves. Diffraction and reflection coefficients are calculated using experimental data on transverse wave propagation in porous media and in an elastic halfspace. On the basis of the dissipative and damping properties and the thickness of the porous soil layer, ground motion accelerograms are calculated for a free surface with given parameters using accelerograms of the Apr. 18, 1940, El Centro earthquake.

3.5-7 Gogeliya, T. I., **Problems of seismic vibrations in soil layers with variable thickness** (Voprosy seismicheskikh

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kolebanii gruntovoi tolshchi s peremennoi moshchnostyu, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 49–54.

The finite element method is employed to calculate the influence of complex engineering and geological conditions on seismic waves. Relative acceleration of surface particles is computed for a multilayered cross section of variable thickness using the accelerograms of five major earthquakes in the U.S. and a computer program which uses triangular approximations.

3.5-8 Odishariya, A. V. and Khomerki, G. V., **Accelerograms of strong earthquakes for rock base calculated on the basis of records in soft soils** (Akselerogrammy razrushitelnykh zemletryasenii dlya skalnogo osnovaniya, postroennye po instrumentalnym zapisam na myagkikh gruntakh, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 41–48.

Accelerograms recorded in porous soils can be modified for conditions of rock base. The method is applicable for an arbitrary number of layers, given the necessary information on the geological profile of the soil. A typical accelerogram is calculated for the case of a single-layer rock base with an underlying bedrock stratum. The calculation utilizes the average values of seismic wave velocities in sand and clay with various levels of moisture content and plasticity.

3.5-9 Puchkov, S. V., **On developments in investigations of the effects of surface topography in seismic microzoning** (O razvitii issledovanii po uchetu relefa mestnosti pri seismicheskom mikroraionirovanii, in Russian), *Byulletin po inzhenernoi seismologii, 8*, 1973, 39–45.

Two methods of investigation for instrumental seismic microzoning are outlined. One is applicable to lowland regions and the other to mountainous areas in seismically active zones. The effects of surface topography on earthquake intensity in mountainous seismic areas are discussed. Macroseismic data on structural damage in buildings with respect to local surface topography are presented. Results of instrumental observations of weak earthquakes under various types of local surface topography are described. A hill profile with uniform seismic resistance is considered. An increase in seismic intensities from the bottom to the top of the hill is demonstrated. Variations in earthquake intensity are considered for another location consisting of a lower and an upper terrace of a river valley.

● **3.5-10** Hattori, S. and Kubotera, A., **Analyses of seismic waves on a soft ground**, *Bulletin of the International Institute of Seismology and Earthquake Engineering*, 13, 1975, 9–22.

Seismic records of 33 earthquakes detected at Uchinomaki inside the caldera of the volcano Aso, where the accumulated soft layer is comparatively thick, are analyzed. The predominant period of seismic waves is around 2.5 ± 0.3 sec, which is consistent with that of microtremors at Uchinomaki. There is no systematic deviation of the predominant period arising from the difference in the direction to the epicenter from the observation point. It also is difficult to see a distinct relationship between the magnitude of earthquakes and the predominant period. Accordingly, it seems that the period characteristics of seismic records in a soft ground may be estimated from those of microtremors at the same place.

3.5-11 Okano, K. and Yamazaki, J., **Characteristics of earthquake motions on various geological formations** (in Japanese), *Zisin, Journal of the Seismological Society of Japan*, 28, 2, Aug. 1975, 201–206.

Simultaneous observations were carried out at Abuyama on bedrock, at Nisseki on diluvium, and at Aino and Tonda on alluvium, using vertical seismographs with the same frequency response and magnification. As is generally known, earthquake motions show strong attenuation on bedrock, last the longest on alluvium and are of intermediate duration on diluvium. However, it is noted that the vibration energy concentrates at the time of S-wave arrival on diluvium. An earthquake disaster which occurred on a hillside region may have been caused by an energy concentration of this type.

● **3.5-12** Seed, H. B. *et al.*, **Relationships between maximum acceleration, maximum velocity, distance from source and local site conditions for moderately strong earthquakes**, *EERC 75-17*, Earthquake Engineering Research Center, Univ. of California, Berkeley, July 1975, 45. (*NTIS Accession No. PB 248 172*)

This report presents the results of a study to determine the influence of local geologic conditions on the attenuation of peak accelerations and peak velocities, with increasing distance from the source of energy release for earthquakes with a magnitude of about 6.5 occurring in the western part of the United States. While the results can only be considered to be strictly applicable to these conditions, it is hoped that they can also serve as a guide to possible relationships between peak accelerations and peak velocities which may be expected for earthquakes of higher magnitudes occurring in different locations, and thereby serve a useful purpose in the difficult task of predicting the likely characteristics of earthquake ground motions in different geologic settings. In this respect, however, it should be noted that while near epicentral values for higher magnitude earthquakes may not change significantly, different attenuation rates, both for peak velocity and peak acceleration are to be expected for earthquakes with different magnitudes and in different geologic zones. The good degree of agreement between the results of this study and those of other investigators, however, gives added

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confidence that the results might be expected to provide a realistic basis for assessing the characteristics of earthquake ground motions for a wide range of soil and geologic conditions.

● 3.5-13 Johnson, J. A., **Site and source effects on ground motion in Managua, Nicaragua,** *UCLA-ENG-7536,* School of Engineering and Applied Science, Univ. of California, Los Angeles, May 1975, 130.

Critical factors in the design of engineering structures are the effects of the source and local site geologic conditions on ground motion induced by strong earthquakes. Accelerograms recorded at several locations in Managua, Nicaragua, offer an opportunity to examine these factors in the vicinity of the causative fault.

Research was conducted to test the adequacy of linear system theory for explaining nearfield ground motion. The theory was tested against ground motion and geologic data, using Fourier transforms and a realistic source representation. Body wave subsurface transfer functions were considered appropriate for use because of (1) Managua's relatively simple near surface geology, (2) the proximity of the accelerograph sites to the causative faults and (3) the lack of surface faulting for most of the events studied.

In order to quantify various parameters of the system model, it was necessary to develop procedures to determine (1) the general frequency characteristics of the source, including corner frequency, (2) the predominant period of the recording sites, as a function of strain level and (3) the thickness of the near surface geologic materials which strongly influence ground motion.

Utilization of the above results was made in conjunction with the complete system model, incorporating a source model and travel path and subsurface transfer functions, to successfully estimate damping and the spectral content of ground motion in the linear and nonlinear range of soil behavior. A comparison of recorded and calculated surface Fourier transforms indicated that, in the near field, the major spectral characteristics of the source and site (i.e., corner frequency and predominant frequency of the site) can be visually estimated.

Two subsurface transfer functions were developed for each of two sites in Managua, one each in the linear range and the nonlinear ranges of soil behavior. These are believed to be useful for future ground motion studies in Managua.

In addition, two different methods were used to calculate ground motion without a source function, using recorded data and transfer functions at a site in downtown Managua. One method required the use of geologic data and recorded main shock data at one site. The other method relied heavily on small ground motion data simultaneously recorded at the two sites. The first of these proved to be the more useful; computational problems limited the use of the second.

3.6 Seismic Site Surveys

3.6-1 Stevens, A. E. and Milne, W. G., **A study of seismic risk near pipeline corridors in northwestern Canada and eastern Alaska,** *Canadian Journal of Earth Sciences,* 11, *1,* Jan. 1974, 147-164.

Seismic risk in the Yukon Territory and adjacent areas of the western Northwest Territories and eastern Alaska is evaluated from locations and magnitudes of earthquakes in northern Canada and Alaska from 1899 to 1970. Contour maps illustrate strain release and also predicted accelerations on firm soil for return periods of 30, 50 and 100 years. Calculated values of these risk parameters may vary by a factor of two or more from actual values due to the short earthquake history of the region studied, uncertainties in location and magnitude of past large earthquakes, lack of measured ground accelerations in the regions and the unknown modifying influence of soil and subsoil materials.

Seismic risk may be significant for parts of the Mackenzie Valley pipeline corridor in the vicinity of Fort McPherson between mile 700 (east of Arctic Red River, Northwest Territories) and mile 850 (east of Old Crow, Yukon Territory).

● 3.6-2 Werner, S. D., **Evaluation of earthquake ground-motion characteristics at nuclear plant sites,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 462-473.

This paper describes how local soil effects can be considered along with available measured records to provide earthquake ground motion specifications consistent with requirements set forth in the current seismic and geologic siting criteria document for nuclear power plants. Current technology for estimating ground motions is assessed; a general procedure is described for specifying vibratory ground motions for nuclear plant design purposes.

3.6-3 Hochstein, M. P. and Davey, F. J., **Seismic measurements in Wellington Harbour,** *Journal of the Royal Society of New Zealand,* 4, 2, 1974, 123-140.

Seismic surveys in Wellington Harbour (Port Nicholson) show that the greywacke basement under the harbor is an undulating erosional surface which has been depressed to a depth of about 400 m in the northwestern part. For most of the harbor the basement lies at a depth of 200 to 300 m. The depression is likely to be a fault-angle depres-

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sion caused by tilting in a westerly direction. No signs of faults or fault-block structures were found in the basement under the harbor. A ridge of basement rocks with high seismic velocity crosses the harbor and crops out at Somes Island and Miramar Peninsula. It is inferred that this ridge and other morphological features in the Wellington area aligned approximately north-south are not of tectonic origin but are erosional features.

The seismic velocity structure of rocks in the direct vicinity of the transcurrent Wellington Fault, aligned along the northwestern side of the harbor, is not known in detail. The crush zone of the Wellington Fault is, however, likely to be about 500 to 1000 m wide under the harbor, and this zone has a subsurface slope about 30° to 50°. On land, near Thorndon and at Petone, the crush zone is about 200 to 400 m wide. The inferred widening of the fault zone under the harbor is probably a consequence of the curving of the Wellington Fault in this region.

● 3.6-4 Bugaev, E. G. and Minaev, N. M., **Observations of ground motions at the Chirkei Dam during weak earthquakes and explosions** (Nablyudenie seismovzryvnykh kolebanii v stvore Chirkeiskoi plotiny pri slabykh zemletryaseniyakh i vzryve, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 87–91.

Ground motion recordings obtained in canyon walls during explosions are analyzed. Good agreement is found between recordings obtained in small earthquakes and in explosions. In the opinion of the authors, strong, distant explosions may be useful in seismic microzoning of dam construction sites.

● 3.6-5 Krasnikov, N. D., **Investigations of elasto-plastic properties of soils for seismic microzoning of construction sites** (Issledovaniya dlya seismomikroraioniro-vaniya ploshchadok stroitelstva s uchetom uprugo-plasticheskikh svoistv gruntov, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 97–102.

An attempt is made to describe the plastic and elastoplastic response of soils to traveling seismic waves due to explosions. The necessity for including the plastic and elasto-plastic properties of soils in seismic microzoning of construction sites is pointed out.

● 3.6-6 Golubyatnikov, V. L. *et al.*, **Spectral-time analysis of local and nearby earthquakes from local zones surrounding the Golovnaya Hydroelectric Power Plant** (Spektralno-vremennyi analiz mestnykh i blizkikh zemletryasenii iz ochagovykh zon okruzhayushchikh plotinu Golovnoi GES, in Russian), *Seismostoikost plotin, 3,* 1975, 23–47.

Dynamic response characteristics for the region surrounding the Golovnaya Hydroelectric Power Plant are investigated. Seismic activity in the area immediately surrounding the dam is rather low. Highly active epicentral zones are found to the north, northeast and southeast of the dam. The authors regard the results of this paper as an experimental basis for a quantitative analysis of seismic excitations of the dam.

● 3.6-7 Nivargikar, V. R. and Christian, J. T., **Geotechnical considerations for siting nuclear power plants,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 1–6.

Site selection for a nuclear power plant requires a thorough and systematic study of vibratory ground motion at the site because of the hazards to public health and safety in case of an accident. This paper summarizes the necessary basic geologic and seismic information that should be compiled and evaluated in order to establish the design seismicity of the site, consistent with the current (1974) engineering practice in the U.S.A.

Discussed are the procedures and limitations of the presently used techniques in assessing the design earthquake accelerations applicable to the site based on correlations of intensity and associated acceleration. It is recommended that velocity is a better measure to correlate with earthquake intensity than acceleration.

● 3.6-8 Golovin, V. A. *et al.*, **Seismic risk evaluation for Inguri Hydroelectric Station,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 2, Nov. 1974, 38–42.

The paper deals with the methods for evaluating the seismicity of the Inguri Power Station region. After evaluating the parameters of oscillations at the site, the authors determine the seismic effect in accordance with Medvedev's instrumental scale. The method of using synthetic records for simulating the most probable ground motion at a site is discussed.

● 3.6-9 Cornell, C. A. and Vanmarcke, E. H., **Seismic risk analysis for offshore structures,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2350, May 1975, 145–151.

The paper reviews recent work in the area of seismic risk evaluation, with particular reference to longer-period structures such as deepwater offshore oil production platforms. The method combines information about earthquake occurrence in time and space (based on both historical and geological data) and attenuation of motion intensity to yield probabilistic statements about the seismic threat at a site of a structure. Its output takes the form of a plot of mean return period versus either site intensity, or maximum ground motion, or response spectrum value.

● **3.6-10** Page, R. A., **Evaluation of seismicity and earthquake shaking at offshore sites,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2354, May 1975, 179-190.

This paper discusses various methods and techniques used by the seismologist to evaluate seismicity and ground shaking at offshore sites. The discussion is illustrated with examples from the continental shelf area in the Gulf of Alaska--a region under consideration for petroleum lease sales and a region of extreme earthquake hazard.

● **3.6-11** Severy, N. I. *et al.,* **In-progress seismic monitoring at a nuclear power plant site,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 1, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

Dames and Moore, international consultants in the earth sciences, at the request of the Virginia Electric and Power Co., has been monitoring microearthquake activity at the North Anna Power Station in central Virginia. The use of such a network is a state-of-the-art engineering application of seismology. The network is providing information on the number, magnitude and spatial location of microearthquakes. The monitoring, required by the U.S. Nuclear Regulatory Commission, should in time demonstrate that strain release is not occurring on a fault zone in the reactor site area.

● **3.6-12** Soydemir, C. and Gürpinar, A., **A geodynamical evaluation of the Elbistan power plant site,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 16, 15. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this geodynamic investigation for the Elbistan-Afsin geological basin in southeastern Turkey, where a major power plant is under construction, the potential contribution of a uniquely sandwiched very soft-soft formation between two stiff-hard layers constituting the subsoil profile has been studied with regard to the spectral characteristics of the ground motion. For the study, a design earthquake has been established through geoseismic and statistical considerations. It is observed that the spectral characteristics of the ground motion are substantially influenced by the presence of the sandwich formation as well as the relative magnitude of the deformation moduli considered for the upper crust layer.

● **3.6-13** Kunar, R. R., **Optimum siting in seismic regions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 164, 7. (For a full bibliographic citation see Abstract No. 1.2-8.)

The siting of important structures in seismic regions results from a number of practical, economical, ecological and geological considerations which can generally reduce a large region to a single smaller region within which the structure may be sited. This paper proposes an automated method of finding the optimum location for the site within any such defined region, so that the risk to a structure at the site from earthquakes in the vicinity is minimized. The risk is quantified as the annual probability of exceeding a given level of peak ground acceleration, and the design variables of the optimization problem are taken as the site coordinates. The constraints are simple linear constraints which represent the boundaries within which the site must be located. The numerical solution of the optimization problem adopts a penalty function approach and uses a conjugate direction method to solve the resulting unconstrained minimization problem. A simple example is presented to illustrate the applicability of the method.

● **3.6-14** Tezcan, S. S. and Durgunoglu, H. T., **Soil amplification survey for the Sogutlucesme viaducts, Istanbul,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 35, 8. (For a full bibliographic citation see Abstract No. 1.2-8.)

Results of the geotechnical, geophysical and soil amplification studies are presented for the site of Sögütlüçeşme Railway viaducts, located approximately six kilometers south of the Istanbul Bogaziçi suspension bridge.

Geometry of soil layers as well as their physical and mechanical properties are determined through a series of borehole investigations, laboratory tests and geophysical measurements. Microtremor records also are taken for purposes of evaluating the predominant periods of the site for small amplitude vibrations. A nonlinear soil amplification analysis is performed by considering a train of upward propagating shear waves. Recommendations are made for earthquake design purposes.

3.6-15 Skorik, L. A., **Response spectra of strong earthquakes near the Nurek Hydroelectric Power Plant** (Spektry reaktsii silnykh zemletryasenii dlya stvora Nurekskoi GES, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki, 87,* 1973, 49-51.

Seismometric data obtained in the region of the Nurek Hydroelectric Power Plant are presented. Multi-pendulum seismometers of the type AIS-2 were used to record earthquakes. The instrumentation was suitable for processing data on seismic vibrations with periods between .05 sec and 1.1 sec. Response spectra of strong-motion earthquakes (magnitude 3 to 4) are obtained for limestone and sandstone.

● **3.6-16** Oliveira, C. S., **Seismic risk analysis for a site and a metropolitan area,** *EERC 75-3,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1975, 198. (NTIS Accession No. PB 248 134)

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A general probabilistic methodology for handling the concept of seismic risk analysis as a measure of losses of life and property suffered by a metropolitan area during a given period of time is presented. The advantages of developing this kind of model are analyzed for those cases where decision-making involves global risks.

Earthquake generation is considered as a stochastic point process random in time, space and magnitude and the earthquake ground motion is considered as a continuous time parameter stochastic process. Attenuation laws include, in a deterministic way, the changes in the predominant period of ground motion with distance and magnitude and, in a random way, an error term. The final probability distribution of maximum response of a one-degree-of-freedom system considering both the randomness of intensity and the randomness of response is studied. For low risks ($<10^{-3}$), the final distribution has to be computed using the distributions of intensity and response and no longer is it valid to consider only the distribution of intensity and the mean value of maximum response. Probability distributions of the response spectra at a given site are derived for the above conditions and the results are compared with other studies. The influence of soil properties with markedly nonlinear behavior is also analyzed under certain conditions.

The damage ratio function is the fundamental unit that induces material and life losses through a metropolitan area after making use of local and spatial morphologies. It is based on the response of a building represented by a one degree-of-freedom with resisting properties characterized by two random variables, yield and collapse. Direct and indirect losses are related to the damage ratio and assembled together in an individual loss function. Its integration over an entire metropolitan area gives the global loss function which is then corrected to include the global consequences of earthquakes.

The combination of randomness in time, space, and magnitude with randomness in the global loss function for a given earthquake is formally achieved through a multiple convolution technique. Here, simulation methods are used. Space correlations through the metropolitan area are considered in a second moment format of the global risk function for the metropolitan area.

A general discussion on the analysis of decision-making applied to a metropolitan area is made and emphasis is given to the following points: solution of Chapman-Kolmogorov equations of a continuous time-parameter, continuous states stochastic process, optimization of code regulations, planning of a new town, identifications of zones of higher potential damage, construction policy after the occurrence of a destructive earthquake and risk for lifeline systems.

● 3.6-17 Kiureghian, A. D. and Ang, A. H.-S., **A line source model for seismic risk analysis,** *UILU-ENG-75-2023, Structural Research Series No. 419,* Univ. of Illinois, Urbana, Oct. 1975, 134.

A line source model for the analysis of seismic risk is developed. The proposed model can be used to evaluate the probability distribution of future ground motions at a site. Based on the model, the sensitivities of the seismic risk to relevant parameters are examined. Results from the line source model are compared with those of point source models, and the significance of assuming earthquakes originating in line sources rather than point sources is examined. The uncertainties in seismic risk evaluation are analyzed, and methods are proposed for including these uncertainties in the final risk evaluation.

Specific application of the line-source model is demonstrated for the seismic risk analysis of San Francisco, California, and San Juan, Puerto Rico. The calculated results for these sites were compared with the corresponding risks estimated from historical records. Finally the concept of risk-consistent response spectra is introduced and a procedure for their development is suggested; such spectra for San Francisco and San Juan are developed.

● 3.6-18 Veneziano, D., **Probabilistic and statistical models for seismic risk analysis,** *MIT-CE R75-34,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, July 1975, 156.

A number of models for engineering seismic risk analysis are proposed and compared. In all cases, uncertainties are included both on the seismic demand at the site, and on the seismic resistance of the facility. Particular attention is given to the effects of inductive uncertainty on the model parameters, which is due to limited available information. These parameters include the mean occurrence rate of seismic events, the "decay rate" of the frequency-site intensity law, the mean value and the variance of the resistance distribution. The results from the models are compared with currently used approximations, which are found to be unconservative. A numerical example is presented, dealing with the estimation of seismic risk for nuclear power plants located in Massachusetts.

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4. Strong Motion Seismometry

4.1 Instrumentation

4.1-1 Borisevich, E. S. *et al.*, **Instruments for the recording of major earthquakes,** *Physics of the Solid Earth, 10,* Oct. 1974, 688-693.

Various types of instruments for the recording of earthquakes between 2-10 intensity points on the MSK-64 scale, in the frequency range of 0-30 Hz, have been developed at the Inst. of Earth Physics of the U.S.S.R. These instruments are used under both stationary and field conditions, particularly in the recording of aftershocks in the epicentral zones of major earthquakes. In the past eight years, recordings of several major earthquakes and hundreds of their aftershocks have been made and processed.

● 4.1-2 Bolt, B. A. and Hudson, D. E., **Seismic instrumentation of dams,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT11,* Proc. Paper 11697, Nov. 1975, 1095-1104.

The desirability of installing seismic instruments on and near major dams is explained. Two types of instruments are required: (1) strong-motion accelerographs for recording potentially destructive ground shaking and resulting dam vibrations; and (2) sensitive seismographs for determining the local seismicity. A minimum of two strong-motion accelerographs should be installed on the dam and a minimum of two should be installed in the immediate vicinity of the dam. Each accelerograph should record three components of motion, should have a natural frequency of approximately 20 Hz, and a recording speed of approx. 1 cm/sec. The sensitive seismographs are intended to record the local seismicity in the vicinity of the dam site before construction, and to detect any changes in seismicity during reservoir filling. A minimum of three seismographs is recommended for installation in the vicinity of the dam site. A vertical-component seismometer (1 Hz - 5 Hz) with visual recorder and approximately 10,000 magnification at 1 Hz is recommended.

● 4.1-3 Zaslavskii, Yu. L. and Aleksandrova, N. M., **Classification and analysis of the failures of the seismic data collection system at the dam of the Golovnaya Hydroelectric Power Plant** (Klassifikatsiya i analiz otkazov registratsionnogo kompleksa inzhenernoseismometricheskoi sluzhby plotiny Golovnoi GES, in Russian), *Seismostoikost plotin, 3,* 1975, 56-78.

Typical breakdowns of the seismic data collection system at the dam of the Golovnaya Hydroelectric Power Plant were classified, and the quality of information lost as a result was evaluated during a four-year study. Measures intended to increase the reliability of such systems are proposed.

● 4.1-4 Rozenberg, I. M., **Triggering mechanisms for earthquake recording devices** (Puskovye ustroistva dlya seismometricheskoi apparatury zhdushchogo tipa, in Russian), *Seismostoikost plotin, 3,* 1975, 79-91.

The requirements for triggering mechanisms of earthquake recording devices are considered. The history of these devices, various refinements and the present state-of-the-art in the U.S.S.R. and abroad are discussed.

● 4.1-5 Fremd, V. M. and Shteinberg, V. V., **Ground motion and instrumentation for recording strong earthquakes** (Kolebaniya grunta i apparatura dlya zapisi silnykh zemletryasenii, in Russian), *Byulleten po inzhenernoi seismologii, 9,* 1975, 125-136.

Records of about 40 of the strongest earthquakes in history are analyzed. Maximum ground displacement, velocity and acceleration do not account for the macroseismic intensity of earthquakes. The parameters of existing

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instruments for recording strong earthquakes are compared with ground motion parameters.

● 4.1-6 Blakely, R. F., Ellis, C. R. and Martin, H. J., **The measurement of seismographic records using a computer-controlled film scanner,** *Bulletin of the Seismological Society of America*, **65**, *1*, Feb. 1975, 227–233.

A semi-automatic system to digitize seismographic records is described. Photographic images of the records are digitized using a cathode-ray-tube film scanner that is controlled by a computer. An operator, interacting with the computer through a display console, supervises the overall data collection and can intervene in the search for traces and in the digitization of the data whenever he feels that it is necessary.

● 4.1-7 Bolt, B. A. and Hudson, D. E., **Seismic instrumentation of dams,** Committee on Earthquakes, United States Committee on Large Dams, Pasadena, Apr. 1975, 20.

Minimum instrument requirements are recommended to cover two types of earthquake problems which can occur in dams: earthquake damage and reservoir-induced seismicity. Since different types of measurement are required for the two situations, the subject is treated under the headings: (1) Strong-Motion Instrumentation and (2) Local Seismograph Networks.

4.2 Regional Data Collection Systems

4.2-1 Kondorskaya, N. V., Aranovich, Z. I. and Starovoyt, O. Ye., **State and perspectives of the development of seismic observations in the USSR,** *Physics of the Solid Earth, 10,* Oct. 1974, 673–675.

The current state and direction of progress for improving seismic observational systems in the U.S.S.R. in the last decade are considered and programs of further work are suggested.

● 4.2-2 **The first annual report of the strong-motion instrumentation program (1972-1973),** *Special Report 108,* California Div. of Mines and Geology, Sacramento, Mar. 1974, 13.

The report briefly describes the State of California's Strong-Motion Instrumentation Program and the actions taken by the Strong-Motion Advisory Board. Also included in the report are listings of the areas in the state where 40 strong-motion accelerographs were installed during 1972–73 and the areas where instruments were to be installed during the 1973–74 fiscal year.

● 4.2-3 Dielman, R. J., Hanks, T. C. and Trifunac, M. D., **An array of strong-motion accelerographs in Bear Valley, California,** *Bulletin of the Seismological Society of America,* **65**, *1,* Feb. 1975, 1–12.

Fifteen strong-motion accelerographs, each with the capability of writing the WWVB absolute time code on the recorded accelerogram, have been deployed in an elliptical array, at a station spacing of several kilometers, along the San Andreas Fault in the Bear Valley region of central California. Ten accelerograms were obtained for the June 22, 1973, earthquake ($M = 3.9$), located near the center of the array. Preliminary analyses of these accelerograms support previous suggestions that the crystalline rocks of the Gabilan Range possess higher material velocities and lower intrinsic absorption than do the Cretaceous and Cenozoic sedimentary rocks northeast of the fault zone. These accelerograms clearly indicate that a strong-motion accelerograph array of this sort can provide the basic data for source mechanism, wave propagation, and local ground-motion studies for earthquakes with magnitudes as small as 3.5–4.0.

● 4.2-4 Mihailov, V. and Kirijas, T., **Establishment of strong motion network in Yugoslavia,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 7, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Yugoslavia is a country which during the past has often been subjected to disastrous earthquakes. Many of its regions have been subjected to the destructive effects of earthquakes several times. Because of the general need for ground motion data to improve earthquake-resistant design and to reduce earthquake hazards on a worldwide basis, as well as the need to study the intense seismicity of Yugoslavia, a project, entitled "Installation of Strong Motion Instrument Network on the Territory of Yugoslavia," was begun in early 1972. The project has been conducted by the Inst. of Earthquake Engineering and Engineering Seismology, Skopje, in cooperation with the California Inst. of Technology, Pasadena.

5. Dynamics of Soils, Rocks and Foundations

5.1 General

5.1-1 Rasulov, Kh. Z., **On critical ground acceleration during earthquakes** (O kriticheskom uskorenii gruntov pri zemletryaseniyakh, in Russian), *Stroitelstvo i arkhitektura Uzbekistana, 6,* 1975, 36–39.

Ideas of N. N. Maslov on critical ground acceleration are used. Critical ground acceleration is defined as the product of the shear resistance of the soil and a certain parameter reflecting the properties of the soil and the character of the dynamic process considered. The relevant formulas and a method for calculating the latter parameter are presented.

● 5.1-2 Keer, L. M., Jabali, H. H. and Chantaramungkorn, K., **Torsional oscillations of a layer bonded to an elastic half-space**, *International Journal of Solids and Structures,* **10**, *1,* Jan. 1974, 1–13.

The problem of a layer bonded to an elastic halfspace, where the layer is driven by torsional oscillations of a bonded rigid circular disk, is solved by means of integral transform techniques. Using a standard technique, the problem is reduced to a Fredholm integral equation of the second kind, the kernel of which involves the calculation of principal value integrals. Dynamic stiffnesses are developed for a range of layer thicknesses, material properties and frequencies.

● 5.1-3 Chandra, B. and Sharma, A. P., **Development of a borehole strainmeter for insitu stress measurements**, *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 351–354.

An in-situ stress measurement instrument was developed at the Earthquake Engineering School, Univ. of Roorkee. The instrument employs an overcoring technique and a single borehole for determination of principal stresses and their directions. The theoretical basis and the details of the instrument are described in the present paper.

5.2 Dynamic Properties of Soils, Rocks and Foundations

● 5.2-1 Roth, W. and Lee, K. L., **A factor of safety approach for evaluating seismic stability of slopes**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 156–165.

A factor of safety approach for evaluating the seismic stability of slopes is presented and demonstrated by examples. The method is a modification of the current method of seismic slope stability analysis which uses finite elements to calculate the stresses and cyclic loading triaxial tests to obtain the strengths of the soil at various locations within the slope or dam.

The factor of safety approach departs from the existing method as follows: (1) It considers any arbitrary specified orientation of possible failure plane. (2) It calculates an overall factor of safety for the entire specified trial failure surface. (Factors of safety for individual elements may also be found.) (3) It includes both static and seismic stress components.

● 5.2-2 Lee, K. L. *et al.*, **Properties of soil in the San Fernando hydraulic fill dams**, *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT8,* Proc. Paper 11527, Aug. 1975, 801–821.

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Results are presented of extensive field and laboratory tests on soils from two old hydraulic fill dams that were damaged during the Feb. 9, 1971, San Fernando earthquake. The data include standard penetration, absolute and relative compaction, relative density, static strength, and cyclic triaxial test results for both the hydraulic fill silty sand and the natural silty and gravelly sand alluvium. The relative densities of the hydraulic fills ranged from about 51%–58% and the relative compaction ranged from about 85%–92% of Modified AASHO maximum density. The relative density of the alluvium was about 65%–70%. Other properties were consistent with previously published data from other similar soils at similar densities.

● 5.2-3 Christian, J. T. and Swiger, W. F., **Statistics of liquefaction and SPT results,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT11,* Proc. Paper 11701, Nov. 1975, 1135–1150.

Data are available on the field behavior of 39 cases involving the occurrence or nonoccurrence of liquefaction during earthquakes. The data from the 39 cases have been examined in a statistical manner to determine the relationships between the field standard penetration test and the occurrence of liquefaction. The data for both relative density and accelerations are lognormally distributed, both for the data as a whole and for the data broken into the two categories of liquefaction and nonliquefaction. Statistics also indicate that the differences between these two categories involve a greater density of the soils at the sites where liquefaction did not occur rather than lower acceleration levels for the earthquakes at those sites. The statistical technique of discriminant analysis is used to locate lines separating liquefiable from nonliquefiable conditions. A line completely enveloping all observed cases of liquefaction is associated with a 90% confidence level, which is very high for the size of the data base.

● 5.2-4 Stephenson, W. R., **Cellular normal modes of alluvium response,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 8, *4,* Dec. 1975, 245–254.

The concept of directed resonance is presented and its occurrence in New Zealand and overseas is documented. It is observed mainly on water-saturated recent alluvium. Analytical procedures for detecting directed resonance effects in earthquake records are outlined. The resonance parameters are shown to be independent of the particular earthquake and highly dependent on local boundaries of the alluvium. Cellular mode resonant response is suggested to be the mechanism generating directed resonance at individual sites and is shown to occur for scale models of alluvial deposits. Experimental apparatus needed to unequivocally confirm the earthquake excitation of cellular resonant modes is described in an appendix.

● 5.2-5 Seleznev, G. S. and Chalkina, G. I., **On a possible interpretation of seismometric data on structures** (Ob odnoi vozmozhnosti interpretatsii materialov inzhenernoseismometricheskikh sluzhb na sooruzheniyakh, in Russian), *Seismostoikost plotin,* 3, 1975, 102–124.

The most important dynamic parameters of the Golovnaya Dam are calculated using records of the data collection system permanently installed in the dam. The mathematical techniques used in the calculation are discussed. The algorithm used to compute the necessary autocorrelational functions and corresponding spectral densities is presented in detail. The computer program used is given in the appendix.

● 5.2-6 Seleznev, G. S. *et al.*, **Comparison of mathematical model and full-scale observations of earth dam response** (Sopostavlenie rezultatov matematicheskogo modelirovaniya s naturnymi nablyudeniyami na zemlyanoi plotine, in Russian), *Seismostoikost plotin,* 3, 1975, 125–133.

Methods of earthquake-resistant dam design are based on a set of assumptions which must be verified experimentally in each case. The most important criteria are provided by full-scale testing of the structure. In this paper a comparison is made of results obtained from analyzing the records of the data collection system permanently installed in the Golovnaya Dam and theoretical results provided by the mathematical model. The comparison shows satisfactory agreement within the limits imposed by the accuracy of the initial data.

● 5.2-7 Kausel, E. and Roesset, J. M., **Dynamic stiffness of circular foundations,** *Journal of the Engineering Mechanics Division, ASCE,* **101**, *EM6,* Proc. Paper 11800, Dec. 1975, 771–785.

A series of parametric studies have been presented, investigating the effects of internal soil damping, Poisson's ratio, layer depth, and embedment on the stiffness functions of circular footings subjected to dynamic forces. The effect of having a finite layer of soil on rigid rock is to introduce valleys in the stiffnesses at the resonant frequencies of the stratum. These valleys are smoothed by the presence of internal damping and their position depends on the value of Poisson's ratio. Embedded foundations have an increased static stiffness, but the frequency variations of the stiffness coefficients are not very different from the corresponding curve for surface footings. The most important factor in reproducing adequately the effect of embedment is the evaluation of the static stiffnesses. They are, however, very sensitive to the assumed conditions at the vertical edges (sidewalls welded to the surrounding soil, degree of disturbance of the backfill, etc.). Experimental work to assess these conditions is necessary.

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● **5.2-8** Sharma, K. K., **Evaluation of relative density of cohesionless soils,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 181–188.

One of the major seismic hazards on saturated noncohesive soil deposits is liquefaction, with accompanying ground movements and foundation failures. The basic soil parameter used to evaluate the liquefaction potential is the relative density of sands. Unfortunately, this parameter cannot be determined experimentally with sufficient accuracy. In this paper, several factors affecting the determination of relative density are studied. To evaluate the relative density of any soil stratum, at least two different techniques should be considered.

● **5.2-9** Agrawal, P. K., Gupta, D. C. and Kumar, V., **Finite element analysis for the seismic stability of earth structures,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 189–198.

The pseudo-static approach for evaluation of the seismic stability of slopes cannot take into account the dynamic nature of earthquake loading and the cyclic strength characteristics of soil. Therefore, for some important earth structures, such as the dikes enclosing the ultimate heat sink in a nuclear power plant, the pseudo-static approach is inadequate. Recently, the finite element method of analysis has been used to obtain the seismic response of important earth structures and to evaluate their stability. In this method of analysis, the embankment-foundation system is modeled using finite elements, and the dynamic response of the system is obtained by subjecting it to a given rock motion. The computer program used in the analysis incorporates the strain-dependent soil modulus and damping ratio for each element of the model. The local factor of safety for each element is determined by comparing the induced shear stresses with the corresponding strength obtained from appropriate dynamic triaxial tests.

The authors present a step-by-step procedure, using the finite element method for evaluation of the seismic stability of earth structures. As an example, the seismic stability of a dike is analyzed. Although the finite element technique is generally recognized as taking better account of the variables involved in a seismic stability problem than does the pseudo-static analysis, it is emphasized that the results obtained should be evaluated carefully. The important factors that must be considered in the analytical procedure to arrive at meaningful results are discussed.

● **5.2-10** Miura, N. and Yamanouchi, T., **Effect of water on the behavior of a quartz-rich sand under high stresses,** *Soils and Foundations,* **15,** *4,* Dec. 1975, 23–34.

The effect of water on the mechanical properties of a quartz-rich sand is investigated by using the results obtained from high-pressure triaxial tests on the sand in both dry and saturated states. It is shown that water increases the compressibility and decreases the shear strength of the sand under high pressures and that these phenomena have a close relation with the activation of particle-crushing in the presence of water. The mechanism of the water action on the lowering of particle strength is investigated from a mechano-chemical viewpoint, and it is concluded that the water sensitivity of the sand is probably due to the surface energy change of cracks which would be produced in each particle under high stresses.

● **5.2-11** Ohta, H., Yoshitani, S. and Hata, S., **Anisotropic stress-strain relationship of clay and its application to finite element analysis,** *Soils and Foundations,* **15,** *4,* Dec. 1975, 61–79.

Anisotropically consolidated natural deposits of clay show the stress-strain responses in different ways for the cases of active and passive loadings. This is caused by the anisotropy in initial stress states of normally consolidated or overconsolidated clays. Incremental stress-strain relations of anisotropically preconsolidated clays are derived from their consolidation and dilatancy characteristics with the help of the associated flow rule. Obtained stress-strain relations give reasonable explanations for the anisotropy in mechanical behavior of anisotropically preconsolidated clays. Integrations of the incremental stress-strain relations give the stress-strain relations under specified loading conditions or with some restrictions on the deformation of clay.

The finite element analysis may be one of the most powerful means for analyzing the stress and strain fields in clay layers consolidated anisotropically in which there exist two different patterns of stress-strain response due to the loading systems, active and passive. As an example, the stress and strain fields in normally and anisotropically consolidated clay layers, stressed by a uniform strip load, are computed with the finite element technique using the above mentioned anisotropic stress-strain relations.

● **5.2-12** Nunnally, S. W., Krizek, R. J. and Edil, T. B., **Empirical liquefaction index for sands,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 17, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

Based on a statistical analysis of data from more than 1,000 laboratory tests on four different sands, an empirical liquefaction index is postulated for sands. According to this criterion, the liquefaction void ratio for a given sand can be obtained from correlations with its Bagnold parameters, and this void ratio is compared with the in-situ or natural void ratio to identify the liquefaction potential of the sand.

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Although several subjective engineering judgments are incorporated into the laboratory-developed criterion, its validity and practical usefulness is substantiated to a large degree by its relatively successful application to 22 field situations in which liquefaction behavior due to seismic excitations was observed.

● 5.2-13 Miladinov, D. *et al.*, **Dynamic shear properties of sand,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 26, 12. (For a full bibliographic citation see Abstract No. 1.2-8.)

A series of cyclic loading triaxial and vibration tests was performed on saturated samples of sand to determine the effect of a simulated earthquake and vibratory loading condition upon the sand strength. The loading frequency of 1 to 30 Hz and acceleration of 0.1 to 1.0 g was adopted, and the resulting deformations were recorded.

It was found that when the static strength is less than 0.5 and frequency 20 Hz, soil samples undergo an acceleration of 0.75 g before failure. For larger frequencies, failure occurs under accelerations lower than 0.75 g. The data show that in these soils, in comparison with the original strength, a significant loss of strength will not occur under cyclic loading conditions.

● 5.2-14 Kuribayashi, E., Iwasaki, T. and Tatsuoka, F., **Relative stiffness and damping capacity of soils,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 27, 10. (For a full bibliographic citation see Abstract No. 1.2-8.)

To evaluate the effects of particle characteristics of soils on shear moduli and damping capacities during small strain amplitude vibrations, comprehensive resonant-column tests were conducted. Sixteen materials with a wide range of grain sizes and grain shapes were selected, and tests were conducted on air-dry samples consolidated isotropically. From the test results, it is found that the shear moduli of silts and silty sands are smaller than those of clean sands and that the damping capacities of silts and silty sands are larger than clean sands.

5.2-15 Miura, K., **Effect of replaced soil on the dynamic characteristics of an embedded foundation structure** (in Japanese), *Transactions of the Architectural Institute of Japan, 237,* Nov. 1975, 87-97.

The purpose of this paper is to investigate the relation between the dynamic characteristics of an embedded foundation structure and replaced soil, which is buried to bridge the gap between the sidewall of the structure and the surface stratum. The analysis is performed using three-dimensional wave propagation theory. Many properties of replaced soil which affect the dynamic characteristics of a structure can be considered; but in this paper the numerical investigations are done using hardness and width of replaced soil. It becomes clear from the numerical analysis that these properties of replaced soil influence considerably the dynamic characteristics of an embedded foundation structure.

5.2-16 Gorelik, L. V. and Shalaev, G. I., **Measurement of Rayleigh wave velocity in rockfill** (Izmerenie skorosti releevskikh voln v kamennoi nabroske, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki, 87,* 1973, 35-37.

The methods and results of measuring Rayleigh wave velocity in the rockfill of the Charvak Dam are presented. The measurements were performed at frequencies of 50, 100 and 200 Hz.

● 5.2-17 Seed, H. B., Martin, P. P. and Lysmer, J., **The generation and dissipation of pore water pressures during soil liquefaction,** *EERC 75-26,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1975, 47. (NTIS Accession No. PB 252 648)

An analytical procedure is presented for evaluating the general characteristics of pore water pressure buildup and subsequent dissipation in sand deposits both during and following a period of earthquake shaking. It is shown that in layers of fine sand, excess hydrostatic pressures may persist for an hour or more after an earthquake. However, evidence of subsurface liquefaction may not appear at the ground surface until several minutes after the shaking has stopped and the critical condition at the ground surface may not develop until 10 to 30 minutes after the earthquake. On the other hand, for coarse sands and gravels with no impedance of drainage due to the presence of sand seams or layers, pore pressures generated by earthquake shaking may dissipate so rapidly that no detrimental buildup of pore pressure or a condition approaching liquefaction can develop. Improving the drainage capability of a sand deposit by the installation of a highly pervious continuous drainage system may thus provide an effective means of stabilizing a potentially unstable deposit. Analyses of the type described also provide the means for assessing whether subsurface liquefaction will have any serious effects on structures supported near the ground surface.

● 5.2-18 Chopra, A. K., Chakrabarti, P. and Dasgupta, G., **Frequency dependent stiffness matrices for viscoelastic halfplane foundations,** *EERC 75-22,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1975, 129. (NTIS Accession No. PB 248 121/AS)

Numerical results are presented for frequency-dependent, complex-valued stiffness influence coefficients for a homogeneous, isotropic, linearly viscoelastic halfspace in plane strain or generalized plane stress. These influence coefficients, defined for uniformly spaced nodal points at

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the surface, are obtained from solutions of two boundary value problems, associated with unit harmonic displacements prescribed separately in each of the two degrees-of-freedom of one nodal point with all other nodal points kept fixed. Results for two viscoelastic models are included: Voigt solid and constant hysteretic solid. A method is presented to determine from these results the frequency-dependent, complex-valued foundation stiffness matrix associated with the nodal points at the base of the structure. Utilizing the results of this work, the earthquake response of a structure, idealized as a two-dimensional finite element system, on the surface of a viscoelastic halfspace in plane strain or generalized plane stress can be analyzed by the substructure method. Because the boundary value problems were solved for unit displacements at individual nodal points on the surface of the foundation, it would not be necessary to limit the base of the structure to a rigid plate.

● 5.2-19 Seed, H. B., Mori, K. and Chan, C. K., **Influence of seismic history on the liquefaction characteristics of sands**, *EERC 75-25*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1975, 33.

This report describes studies which were conducted to clarify the effects of seismic history on the liquefaction characteristics of saturated sands. It has been shown both analytically and experimentally that deposits of sand subjected to low magnitude earthquakes, which are not sufficiently strong to cause liquefaction, will develop an increased resistance to liquefaction in subsequent earthquakes even though they may undergo no significant change in density. This increased resistance may be due to changes in structure of the sand grain system or an increase in the lateral earth pressure coefficient, K_o. Accordingly, in order to determine the liquefaction characteristics of a sand, it is necessary to perform tests on samples having the same density and structure as the in-situ material and conduct the tests, whenever possible, with the correct in-situ value of K_o. In practice this is best achieved at the present time by performing tests on undisturbed samples which retain the same density and structure as the in-situ material and applying analytical corrections for any deviation from the desired value of K_o in the test program.

The study also indicates that the standard penetration resistance (or any in-situ measure of penetration resistance) is likely to provide a reasonable index of the liquefaction characteristics of a saturated sand deposit and available data on field performance has been summarized to develop a correlation between penetration resistance and the cyclic stress ratio at which liquefaction has been found to occur in the field.

By combining the results of appropriate test programs as described above with analytical evaluations of the shear stresses developed by any given earthquake in a sand deposit, and utilizing the correlations between field performance and relative density as a supplementary guide to probable future performance, it should be possible to arrive at a reasonably good evaluation of the liquefaction potential and the associated potential deformations of a sand deposit. However, it is apparent that good judgment must continue to be an essential ingredient of such evaluations at the current state of knowledge.

● 5.2-20 Seed, H. B. *et al.*, **Representation of irregular stress time histories by equivalent uniform stress series in liquefaction analyses**, *EERC 75-29*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1975, 40. (NTIS Accession No. PB 252 635)

The report presents a rational yet simple procedure for determining the uniform cyclic stress series which is equivalent, from the point of view of soil liquefaction, to any given irregular time history of stresses developed by an earthquake. It is believed that the procedure described will serve this purpose with an adequate degree of accuracy for practical purposes. A study of the stress histories developed by earthquakes with magnitudes ranging from about 5 to 6.3 indicates that a cyclic stress series involving 5 cycles at a uniform stress level of 0.65 τ_{max} provides an adequately conservative representation of such events, when used in conjunction with a conservative choice of design ground motion, suggesting that the use of larger numbers of stress cycles than this would lead to overly conservative estimates of liquefaction potential for most sites subjected to earthquakes of such moderate magnitudes. Appropriate numbers of equivalent uniform stress cycles for earthquakes with various magnitudes are analyzed statistically, and recommendations are made for appropriate numbers of cycles for use in engineering design.

● 5.2-21 Vinson, T. S., **Cyclic triaxial test equipment to evaluate dynamic properties of frozen soils**, *MSU-CE-75-1*, Div. of Engineering Research, Michigan State Univ., East Lansing, Mar. 1975, 37. (NTIS Accession No. PB 242 419)

To establish the response interaction between a soil deposit and a structure during an earthquake, two soil properties are required: (1) the dynamic shear modulus and (2) the damping factor. For unfrozen soils these properties have been determined by several investigators, and design equations and curves to establish the properties for representative soil types have been developed. For frozen soils, only limited work has been done to evaluate these properties in a test range that would not be useful in earthquake response analyses. Thus, an engineer confronted with a seismic design problem involving frozen soils cannot use existing analytic techniques to predict response interactions because the necessary properties of frozen soils have not been determined.

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The results of a research program to (1) develop test equipment to evaluate the shear moduli and damping factors of frozen soils for use in ground response analyses during earthquakes, and (2) develop a research plan to investigate parameters that might influence shear moduli and damping factors of frozen soils are presented. The equipment configuration developed consists of an MTS electrohydraulic closed loop cyclic triaxial device coupled with a cold bath and refrigeration unit. The system is capable of subjecting frozen soil samples to confining pressures up to 700 kN/m^2, shear strains in the range of 10^{-3}% to 1%, frequencies in the range of 1 to 5 Hz, and temperatures over a range of 0°C to -10°C.

5.2-22 Miura, K., **On dynamic characteristics of an embedded structure with rounded corners rectangular section (Part I)** (in Japanese), *Transactions of the Architectural Institute of Japan, 232,* June 1975, 71-80.

A theoretical method is described for analyzing, on the basis of a three-dimensional wave propagation theory, the dynamic characteristics of a structure with a rounded-corner rectangular section which is embedded in a surface stratum of bedrock. The method is approximate, but boundary value problems between the side wall and the surface stratum can be solved with good accuracy by introducing orthogonal functions. As an example, factors for determining the dynamic characteristics of an embedded structure with a square section are calculated. From these numerical results, the equivalent circular radius for a square section might be evaluated.

5.3 Dynamic Behavior of Soils and Rocks

● 5.3-1 Tezcan, S. S. and Çekirge, H. M., **Nonlinear shear wave propagation in layered half-space**, Bogazici University, Istanbul, June 1974, 10.

Nonlinear propagation of shear waves in a horizontally layered halfspace is formulated, assuming a parabolic stress-strain relationship. Closed-form expressions for displacements, stresses and strains are presented using a perturbation technique and considering only the first-order nonlinear terms.

● 5.3-2 Ishihara, K., **Liquefaction of subsurface solids during earthquakes**, *Technocrat,* 7, 5, May 1974, 81-98.

This paper summarizes the results of studies of the liquefaction of sandy ground during earthquakes that have been conducted by the author over the past few years. Case history studies on this subject that were carried out during the major earthquakes in Japan are disclosed for the first time; three soil profiles most prone to liquefaction are described. Principles and methods of laboratory studies of liquefaction are briefly introduced; typical examples of recent test data are shown. In Chapter 3, the methods and techniques of field investigations are described and the interpretation of them in relation to liquefaction prediction is discussed. Finally, a predictive method is presented in which the laboratory test data are incorporated into analyses using the wave propagation method.

● 5.3-3 Wylie, E. B., Streeter, V. L. and Papadakis, C. N., **Transient two-dimensional analysis of soils by latticework,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 166-175.

A shearing stress analysis procedure is presented that solves the soil dynamic equations in a latticework of line elements. The concepts of the method are described; the equations are formulated and placed in a form for numerical solution; and illustrative examples are included to demonstrate the scope and practicality of the method.

● 5.3-4 Youd, T. L., **Liquefaction, flow and associated ground failure,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 146-155.

This paper, a revised and condensed restatement of the contents of U.S. Geological Survey Circular 688, presents explicit definitions of liquefaction and of several related terms which were derived from behavior observed in laboratory tests. These definitions are then used to explain the relation between liquefaction and consequent ground failures, to further identify and clarify the types of ground failures triggered by liquefaction and to examine the relevance of currently available methods for evaluating liquefaction potential.

● 5.3-5 Luco, J. E., Trifunac, M. D. and Udwadia, F. E., **An experimental study of ground deformations caused by soil-structure interaction,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 136-145.

Detailed measurements of the surface ground motion generated by forced vibrations of the nine-story Millikan Library building on the campus of the California Inst. of Technology are described. The three components of the displacement field were measured at 100 points located in the immediate neighborhood of the building and at over 250 points distributed in the Pasadena area at distances up to four miles from the Millikan Library. The measurements were conducted at the lowest resonant frequencies of the building-foundation system in both the north-south (~ 1.8 Hz) and east-west (~ 1.3 Hz) directions. The excitation was provided by a vibration generator mounted on the roof of the building. Preliminary analysis of the motion recorded in the near and far field indicates the potential of this experi-

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mental approach in evaluating the effects of soil-structure interaction as well as the effects of local site conditions on surface ground motion.

● 5.3-6 Bazant, Z. P. and Krizek, R. J., **Saturated sand as inelastic two-phase medium,** *Journal of the Engineering Mechanics Division, ASCE,* **101,** *EM4,* Proc. Paper 11508, Aug. 1975, 317–332.

The inelastic densification produced by shear straining saturated sands is opposed by the elasticity of the pore water and leads to a pore pressure increase, which causes a decrease in the intergranular frictional forces and consequent liquefaction of the sand mass. This inelastic densification is accompanied by an inelastic strain of the fluid phase, and the magnitude of the developed pore-water pressure is the product of the inelastic densification and the densification compliance, the latter of which is approximately equal to the drained compressibility of the sand. The tangent (incremental) elastic moduli are expressed in terms of the drained and undrained compressibilities of the two-phase medium and the compressibilities of water and the solid matter forming the grains. It is demonstrated that the volume change of the grains due to intergranular stresses has a negligible effect on the material parameters, even though it roughly equals the volume change of the grains due to the pore-water pressure, which has an appreciable effect.

● 5.3-7 Martin, G. R., Finn, W. D. L. and Seed, H. B., **Fundamentals of liquefaction under cyclic loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **101,** *GT5,* Proc. Paper 11284, May 1975, 423–438.

The mechanism of progressive pore pressure increase during undrained cyclic simple shear tests on saturated sands has been examined in detail. The concepts developed provide a better understanding of the physical processes leading to liquefaction of horizontal sand deposits during earthquakes. A quantitative relationship between volume changes occurring during drained cyclic tests and the progressive increase of pore water pressure during undrained cyclic tests has been developed. The use of this relationship enables the build-up of pore water pressure during cyclic loading to be computed theoretically using basic effective stress parameters of the sand. The application of the theory to the case of undrained cyclic simple shear tests with uniform stress controlled loading is illustrated. Values of progressive pore water pressure increases predicted theoretically agree reasonably well with the nature of pore water pressure increases observed experimentally.

● 5.3-8 Pyke, R. M., Seed, H. B. and Chan, C. K., **Settlement of sands under multidirectional shaking,** *Journal of the Geotechnical Engineering Division, ASCE,* **101,** *GT4,* Proc. Paper 11251, Apr. 1975, 379–398.

Tests on samples of dry sand subjected to shaking in one, two, and three dimensions show that the settlements caused by multidirectional shaking may be significantly greater than the settlements caused by shaking in one direction only. The settlements caused by combined horizontal motions are about equal to the sum of the settlements caused by the components if they act separately. Vertical motion superimposed on horizontal motion causes an increase in settlements. By using a simple correction factor based on these findings, it is shown that the settlement computed from the results of cyclic simple shear tests and a one-dimensional response analysis agrees well with the observed settlement of a clayey sand fill in the San Fernando earthquake.

● 5.3-9 Seed, H. B. *et al.*, **Dynamic analysis of the slide in the Lower San Fernando Dam during the earthquake of February 9, 1971,** *Journal of the Geotechnical Engineering Division, ASCE,* **101,** *GT9,* Proc. Paper 11541, Sept. 1975, 889–911.

During the San Fernando, California, earthquake of Feb. 9, 1971, a major slide occurred in the upstream slope of the Lower San Fernando Dam. Based on data obtained from tests on undisturbed samples, a detailed dynamic analysis of the seismic stability of the embankment is presented. It is concluded that an analytical procedure incorporating: (1) consideration of the initial static stresses in the embankment; (2) the use of a dynamic finite element analytical procedure to determine the dynamic stresses induced in individual elements of the embankment by the earthquake; (3) the use of cyclic loading triaxial compression test data to determine the response of the soil elements to the induced stresses; and (4) consideration of progressive failure effects provides a satisfactory basis for assessing the stability of the embankment. This type of analysis indicates the development of a zone of liquefaction along the base of the upstream shell that would be sufficiently extensive near the end of the earthquake shaking to lead to a condition of instability.

● 5.3-10 Popova, E. V., **Residual ground deformations in strong earthquakes: Part 2** (Ostatochnye deformatsii gruntov pri silnykh zemletryaseniyakh, chast 2, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 150-205.

Information obtained from published sources is presented in tabular form on residual soil deformations in 49 strong earthquakes in the U.S.A., Japan, China, Mongolia, Iran, India and Chile. Data on geological, hydrogeological and tectonic conditions in the earthquake regions as well as on the size of residual soil deformations, seismic intensities, ground displacement, velocity and acceleration values in nearby soils are included.

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● **5.3-11** Oda, M., **A mechanical and statistical model of granular material,** *Soils and Foundations,* **14,** *1,* Mar. 1974, 13–27.

Using knowledge with regard to the fabric characteristics of granular material and their reorientation during compressional deformation, the author proposes a mechanical and statistical model. The mean value of force acting on a contact is determined as a function of the state of principal stresses and the inclination angles of the normal to the principal stress axes. The relation between the mobilized principal stress ratio and the fabric index of granular material is determined by consideration of the static equilibrium of forces at the contact. The probability of sliding at a contact can be calculated by considering that the forces at the contact are random variables having mean values and standard deviations. The rates of strain in the principal directions are obtained theoretically in terms of the frequency and intensity of sliding and the fabric characters; then the relations between the fabric character, the dilatancy index and the mobilized stress ratio are proposed. The relation between the void ratio and the distribution character of the normal, which must be satisfied at the peak stress state, also is discussed. The theoretical equations accord well with the experimental results by means of the microscope and the thin-section method.

● **5.3-12** Adachi, T. and Okano, M., **A constitutive equation for normally consolidated clay,** *Soils and Foundations,* **14,** *4,* Dec. 1974, 55–73.

Past research conducted to develop constitutive equations for soils has focused on two areas: soil deformation characteristics at the equilibrium state and the rate-sensitive properties of soils. By using Perzyna's theory of elasto-viscoplastic continuum and empirical results, Roscoe's critical state energy theory for clays is extended to explain the rate-sensitive property of clays. The proposed equation more generally describes the behavior of clays, such as creep, stress relaxation and constant strain rate shear processes than the equations of other investigators, although the equation needs refinement. Since the equation is expressed in terms of the second-order tensor field, it can be applied to three-dimensional problems by means of the finite element method.

● **5.3-13** Stephenson, W. R., **An experimental study of normal modes of vibration of saturated alluvium,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 119–126.

An historical account is given of attempts to model the alluvium at one location in New Zealand. The use of microtremor measurements to obtain information about the behavior of alluvium and the failure of the measurements to give useful results are discussed; then the confusion surrounding the use of small earthquakes for the same purpose is considered. A study of small earthquake ground motions reveals important directional features and shows that a comparison of motions at nearby sites should include the effects of cross-component interactions.

It is concluded that the use of the infinite parallel-layer model to describe ground motion is often misleading and that a more accurate model consists of normal mode cells having motions along closed flow lines and directions that are boundary controlled. The motions for the new model are best thought of as "liquid-flow resonance." Small-scale jelly-model tests, which support the new model for alluvium motion, are described. An account also is given of a field setup used in New Zealand for recording small earthquakes. The directional spectra of those small earthquakes recorded up to this point support the new model. The new mechanism for describing the motions of alluvium is called the "cellular mode model." The features of the model have far-reaching implications for structural design; it, therefore, should be studied comprehensively.

● **5.3-14** Ter-Martinosyan, Z. G. and Manvelyan, R. G., **Stresses in rock subjected to local loads and body forces** (Napryazhennoe sostoyanie gornykh massivov pri deistvii mestnoi nagruzki i obemnykh sil, in Russian), *Byulleten po inzhenernoi seismologii, 9,* 1975, 51–57.

A two-dimensional boundary value problem in the theory of elasticity involving seismic and surface forces acting simultaneously on a semi-infinite region with curvilinear boundary is posed and solved. Formulas for calculating stress components and stability factors are given. Examples of calculations are given, and diagrams showing maximum tangential stresses and stability factors are obtained. An analysis of the results and examples is presented.

● **5.3-15** Joyner, W. B. and Chen, A. T. F., **Calculation of nonlinear ground response in earthquakes,** *Bulletin of the Seismological Society of America,* **65,** *5,* Oct. 1975, 1315–1336.

A method is presented for calculating the seismic response of a system of horizontal soil layers. The essential element of the method is a rheological model suggested by Iwan, which takes account of the nonlinear hysteretic behavior of soils and has considerable flexibility for incorporating laboratory results of the dynamic behavior of soils. Finite rigidity is allowed in the underlying elastic medium, permitting energy to be radiated back into the underlying medium. Three alternate ways of integrating the equations of motion are compared, an implicit technique, an explicit technique, and integration along characteristics. An example is set up for comparing the different methods of integration and for comparing the nonlinear solution with a solution based on the widely used equivalent linear assumption. The example consists of a 200-m section of firm alluvium excited at its base by the N21E

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component of the Taft accelerogram multiplied by four to produce a peak acceleration of 0.7 g and a peak velocity of 67 cm/sec. The three techniques of integration give very similar results, but integration along characteristics has the advantage of avoiding spurious high-frequency oscillations in the acceleration time history at the surface. For the chosen example, which has a thick soil column and a strong input motion, the equivalent linear solution underestimates the intensity of surface motion for periods between 0.1 and 0.6 sec by factors exceeding two. The discrepancies, however, would probably be less for input motion of lower intensity. At longer periods the equivalent linear solution is in essential agreement with the nonlinear solution. For the same example both solutions show that, compared to a site with rock at the surface, motion at the surface of the soil is amplified for periods longer than 1.5 sec by as much as a factor of two. At shorter periods the amplitude is reduced.

● 5.3-16 Joyner, W. B., **A method for calculating nonlinear seismic response in two dimensions**, *Bulletin of the Seismological Society of America*, 65, 5, Oct. 1975, 1337-1357.

A method is presented for calculating the seismic response of two-dimensional configurations of soil resting on bedrock. The method, which is based on a rheological model suggested by Iwan, takes account of the nonlinear, hysteretic behavior of soil and offers considerable flexibility for incorporating laboratory data on soil behavior. An approximate treatment of the boundary conditions is employed which permits energy to be radiated into the underlying medium. Examples are shown to illustrate the method.

● 5.3-17 Ishihara, K., Tatsuoka, F. and Yasuda, S., **Undrained deformation and liquefaction of sand under cyclic stresses**, *Soils and Foundations*, 15, *1*, Mar. 1975, 29-44.

The key findings of previous studies on the deformation of sand are reviewed. Then, in summary form, five fundamental postulates are introduced as the bases on which a model of undrained deformation of sand under cyclic loading is to be established. The procedures for assessing pore pressures, shear strains and consequent occurrence of liquefaction during cyclic loading are illustrated on the diagrams based on the above postulates as well as on actual data obtained in the static triaxial tests. The undrained performance of sand predicted by the proposed model was compared with several cyclic triaxial test results conducted under various conditions. These include stress- and strain-controlled tests, static and dynamic tests, and the tests cycled with constant and erratically changing stress amplitude. The comparison disclosed the relevance and applicability of this method of approach.

● 5.3-18 Kuribayashi, E. and Tatsuoka, F., **Brief review of liquefaction during earthquakes in Japan**, *Soils and Foundations*, 15, *4*, Dec. 1975, 81-92.

To correlate actual liquefaction phenomena and site conditions, a literature survey of liquefaction phenomena caused by earthquakes during the last century in Japan was performed. A liquefaction distribution map of Japan and regional maps of Kanto, Nobi and Hokuriku are presented, and the factors in relation to liquefaction are discussed. In the last century liquefaction in subsoils has been observed at some hundred sites during at least 44 earthquakes. The sites were limited only to alluvial deposits and reclaimed lands. Furthermore, it was found that liquefaction occurred repeatedly during different earthquakes in several zones. Estimated JMA intensity scales at liquefied sites were more than the fifth grade, which means maximum acceleration of 80 to 250 gals. The extent of liquefied zones is limited depending on the magnitude of the earthquakes.

● 5.3-19 Nataraja, M. S., **Seismically induced settlements**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 37, 7. (For a full bibliographic citation see Abstract No. 1.2-8.)

There are two basic approaches available for computing seismic settlements. They are based on cyclic simple shear and cyclic triaxial test results. Results of shaking table tests have provided additional insight into the problem. The experimental results presented in this paper show that the pore pressure buildup in silty sands occurs during the first few cycles of shaking rather than the last few. It is concluded that this factor should be taken into account in estimating the magnitude of seismic settlements under important structures, such as nuclear power plants.

● 5.3-20 Dezfulian, H., **Finite element grids for dynamic response analysis**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 39, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

For evaluation of the dynamic response of soil deposits with sloping boundaries, it is necessary to use analytical procedures such as the finite element method. The first step in using this method is idealization of the soil deposit, which involves the division of the original continuum into a finite number of elements of appropriate sizes and shapes, connected at a finite number of nodal points.

In forming a finite element grid, it becomes immediately necessary to choose the extent of the region which is to be represented by the finite elements. This paper reports on criteria developed for choosing the extent of finite element grids to be used in dynamic response analysis of nonuniform soil deposits. The criteria are developed based on a large number of finite element analyses which take

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into account the nonlinear characteristics of soil deposits by using equivalent linear procedures.

5.4 Dynamic Behavior of Soil and Rock Structures

5.4-1 Tolkachnik, S. V., Natarius, Ya. I. and Leshkevin, G. A., **Investigations of vibrations of canyon walls using the finite element method** (Issledovanie kolebanii kanonov metodom konechnykh elementov, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94,* 1974, 25-31.

Free vibrations in canyons regarded as areas of finite size are considered. The goal of these investigations is to obtain quantitative data on relative dynamic displacement of various points of the canyon at an arbitrary moment in time. These data lead to a more exact calculation of the seismic effect on the structure by getting rid of the hypothetical "platform effect," the existence of which is not supported by actual full-scale measurements.

5.4-2 Kovtun, I. N. *et al.*, **Stresses in rock near the source of underground explosions** (Napryazhenno-deformirovannoe sostoyanie porodnogo massiva vokrug ochaga podzemnogo vzryva, in Russian), *Razrabotka rudnykh mestorozhdenii, 20,* 1975, 59-65.

Stresses in rock during underground explosions are investigated. Various mechanisms of fracture zone formation are discussed. The size of cracks depends substantially on rock properties and the size of the explosion.

5.4-3 Stepanov, V. Ya. and Giss, R. E., **On effects of seismic loads on deformation of slopes near the Toktougol Hydroelectric Power Plant** (O vliyanii seismicheskikh nagruzok na deformatsii sklonov v rayone Toktougolskogo gidrouzla, in Russian), *Deformatsiya massivov gornykh porod,* ILIM Publishers, Frunze, U.S.S.R., 1975, 163-170.

Results are presented of experimental investigations of the effects of seismic loads due to explosions on the displacement velocity along cracks of rock masses. Displacements were measured using hydrostatic leveling methods.

● 5.4-4 Tishchenko, V. G. and Popova, E. V., **On dynamic behavior of elongated earth structures** (O dinamicheskikh kharakteristikakh protyazhennykh zemlyanykh sooruzhenii, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 8-19.

Various types of residual deformations occurring in elongated earth structures (e.g., dams, road and railroad embankments) following strong earthquakes are analyzed. The effects of small free horizontal vibrations on deformations of a structure along its longitudinal axis are investigated. The dynamic response of the structure to short-period seismic disturbance is calculated.

● 5.4-5 Puchkov, S. V., **Investigations of the relative stability of various segments of earth dams during seismic excitation** (Issledovanie otnositelnoi ustoichivosti otdelnykh chastei zemlyanykh plotin pri prokhozhdenii seismicheskoi volny, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 103-106.

A method for calculating relative stability of various segments of an earth dam is presented. The method is essentially a microzoning technique for the earth dam, which can lead to the isolation of weakened sections where the probability of failure during strong earthquakes is the greatest. An example of an application of this method is given.

● 5.4-6 Skorik, L. A., **On variations in the dynamic response characteristics of seismic shaking with height along the canyon walls of the Chirkei Hydroelectric Power Plant** (Ob izmenenii chastotno-vremennykh kharakteristik seismicheskikh kolebanii po vysote sklona kanona v strvore Chirkeiskoi GES, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 92-96.

Results of application of the methods of spectral-time analysis to the study of seismic response of canyon walls are presented. The relationship between ground motion intensities and the height of the observation site at various points is investigated.

● 5.4-7 Maletin, A. M., **On calculation of stresses in earth dam** (K opredeleniyu napryazhennogo sostoyaniya zemlyanoi plotiny, in Russian), *Seismostoikost plotin, 3,* 1975, 156-164.

Earth dams are constructed in seismically active regions where earthquake accelerations from 0.1 to 0.4 g may occur. The response of such dams to earthquake excitation is investigated. In order to obtain qualitative results simply, a one-dimensional model is considered.

● 5.4-8 Golubyatnikov, V. L. and Seleznev, G. S., **Time-spectral analysis of the behavior of the dam of the Golovnaya Hydroelectric Power Plant from earthquake and microtremor records** (Spektralno-vremennoe opisanie povedeniya plotiny Golovnoi GES po zapisyam zemletryasenii i mikroseism, in Russian), *Seismostoikost plotin, 3,* 1975, 92-101.

The configuration of the Golovnaya Dam and the geological conditions in the underlying bedrock are rather complex. Both the cross section and the height of the dam vary along the length of the dam. Simultaneous recordings at two observation points were used to investigate the

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dynamic response characteristics of the dam. Due to the complexity of the system investigated, and factors such as wave propagation inside the dam, interaction between the dam and bedrock and wave interference, the results obtained hold only in a statistical sense.

● 5.4-9 Kameswara Rao, N. S. V. and Dasgupta, S. P., **Finite element solution to some plane problems in soil dynamics**, *Finite Element Methods in Engineering*, 511-531. (For a full bibliographic citation see Abstract No. 1.2-1.)

The finite element technique is used to analyze the dynamic response of several idealized soil media. The loading considered is a dynamic strip load, which reduces the problem to a plane strain case. To incorporate the nonlinear behavior of actual soil media, spline functions were used. This permitted a great deal of flexibility in using field data for the analysis. The procedure is based on the concept of functional interpolation through a number of data points. To provide knowledge of actual field behavior, the laterally homogeneous and depth-dependent elastic behavior of a soil also is reported. In all of the above cases, the following contact pressure distributions were assumed at the soil-structure interface: (a) rigid base approximation, (b) uniform pressure and (c) parabolic loading. The footing embedment is considered and its effect on the dynamic soil response is indicated. Side forces on the footing due to existing soil mass also are included in the analysis. The results are presented in graphical form and, where possible, they are compared with existing solutions.

● 5.4-10 Bugaev, E. G. *et al.*, **Behavior of the Chirkei Canyon during aftershocks** (Kolebaniya Chirkeiskogo kanona pri aftershokakh, in Russian), *Byulleten po inzhenernoi seismologii*, *9*, 1975, 99-110.

The strong Dagestan earthquake of May 14, 1970, was followed by a series of aftershocks. They were recorded at ten locations in the canyon near the dam construction site. The observation methods are described and the processing and analysis of data discussed.

● 5.4-11 Mostaghel, N. and Nowroozi, A. A., **Earthquake response of hills**, *Bulletin of the Seismological Society of America*, **65**, *6*, Dec. 1975, 1733-1742.

A hill is represented by a linearly elastic shear beam with an exponentially varying cross section in order to predict its earthquake response. An inequality is proposed through which an upper bound on the amplification factor of the maximum base acceleration may be estimated. The method is applied to Kagel Mountain, the site of the 1971 San Fernando earthquake, and an upper bound on the amplification factor of the maximum base acceleration for the Pacoima Dam site, when subjected to the El Centro earthquake of 1940, is estimated. The results are in good agreement with what may be predicted from the available attenuation curve for the western United States.

● 5.4-12 Ayyar, T. S. R., **Mechanisms involved in the failure of natural slopes and embankments due to earthquakes**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 199-206.

The conventional method for computing the factor of safety of slopes to include earthquake effects, both using slip circle analysis as well as the finite element method, generally involves the use of an additional inertia force as the actuating force. This has only limited application: It gives satisfactory results in cases where the predominant effect of seismicity is to impart an additional inertia force. The classification of slope failures given by Skempton and Hutchinson and Newmark does not take into account the forces causing the failures. In this study, 30 case histories of slope failures due to earthquake effects are reviewed. Among them are some well-documented earthquakes, such as the 1811 New Madrid earthquake, the 1861 Helice earthquake, the 1965 Chilean earthquake, and the 1964 Anchorage and Niigata earthquakes. The reported damage was examined and a classification of the failures attempted.

The mechanisms of failure can be broadly grouped as follows: (i) the earthquake acts as a triggering force on a slope already in critical equilibrium, (ii) the earthquake movements follow new fault movements in bedrock or reactivation of old faults, (iii) the earthquake causes liquefaction of soil resulting in slumping and spreading failure, (iv) the earthquake causes local increase of pore water pressure leading to upward seepage and consequent instability due to reduced effective stress, (v) the earthquake acceleration causes indirect effects, such as lowering of the soil strength in the failure zone, or it results in progressive failure by removal of toe support, and (vi) the earthquake acceleration acts as a direct inertial force causing block translatory movements.

These case histories show that each mechanism is closely linked to the surface features of the damage. Consequently, if the soil characteristics of a region are known and the seismicity can be estimated, it would be possible to predict the type of slope failure. It is hoped that this will lead to more realistic methods of slope stability analysis and to satisfactory remedial measures under different situations.

● 5.4-13 Papadakis, C. N. and Wylie, E. B., **Seismic shear wave propagation through earth dams**, *Soils and Foundations*, **15**, *2*, June 1975, 47-61.

Two methods are presented to study the one-dimensional propagation of seismic shear waves through tapered cross sections of earth dams with truncated crests. The

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earth dam material is assumed to be unsaturated and linear viscoelastic, or nonlinear strain-softening. The shear modulus may be considered to vary with depth or to be constant throughout the dam cross section. A closed-form solution which involves Hankel functions with complex arguments is developed in case the earth dam material is viscoelastic, and the dam base is subjected to harmonic excitations. The method is extended to cases of random seismic vibrations by employing Fourier analysis in conjunction with a least-squares criterion. Response curves are obtained for viscously damped tapered dam cross sections with truncated crests, using the analytical solution developed. The method of characteristics also is used to provide a solution to the shear wave propagation problem. The method of characteristics exhibits versatility in handling different descriptions of dynamic material response, such as "strain-softening" material behavior laws. Three examples are presented to illustrate the application of the two methods and to demonstrate the relative simplicity and flexibility of the method of characteristics.

● **5.4-14** Sarma, S. K., **Seismic stability of earth dams and embankments,** *Géotechnique,* XXV, *4,* Dec. 1975, 743–761.

In the design of earth dams and embankments under earthquake loading conditions, displacements offer a better criterion than a factor of safety on shear strength. The displacement depends on shear strength, inertia forces and pore pressures generated during the earthquake. The model of a rigid block on a plane surface is used to analyze the effect of inertia forces and pore pressures on the stability of an earth dam or embankment during strong earthquakes. The study is based on limit equilibrium principles and the material obeys the Mohr-Coulomb failure criterion with effective stresses. It is shown that by using the pore pressure parameters A and B, the excess pore pressures generated during an earthquake can be accounted for in the effective stress analysis. It is also shown that displacements during an earthquake can be easily calculated by using simple pulses. Several interesting conclusions are drawn and an example of application of the method to earth dams and embankments is given.

● **5.4-15** Birbrayer, A. N., **Analysis of embankment profile changes under seismic impact,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 47, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Studied are the irreversible changes caused by an earthquake in the embankment of a homogeneous dry noncohesive soil. The procedure for deriving the differential equations of motion and the results of the comparison of the calculations with experimental data are presented.

● **5.4-16** Vulpe, A. *et al.,* **Seismic analysis of a rockfill dam,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 48, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Dynamic equilibrium equations for a dam are established by using a Pian-Tabarrok principle along with a hybrid stress finite element model. Based on this formulation, the seismic analysis of a rockfill dam was performed, considering the dam-foundation interaction. Numerical results were obtained for the horizontal and vertical components of the 1952 Taft earthquake.

● **5.4-17** Akay, H. U. and Gülkan, P., **Earthquake analysis of Keban Dam,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 36, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

A dynamic finite element analysis is made for a typical cross section of Keban Dam, one of the largest rockfill dams in the world. The free-vibrational characteristics of the idealized cross section are obtained. Rather than calculating the response to an earthquake recorded elsewhere, an artificial record, which is intended to portray the ground motion in a fairly strong and close event, is produced. Time variations of displacements and stresses at selected locations on the dam are plotted, and the increase in the stresses over "static" values is noted.

● **5.4-18** Seleznev, G. S., Zaslavskij, J. L. and Tschalkina, G. I., **A prediction of earth dam response during earthquakes,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 57, 4. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper a prediction of earth dam behavior during earthquakes is discussed. The actual response of the dam under study generated by the medium-sized earthquake is within the confidence intervals of the predicting quantities.

5.4-19 Turashvili, G. M., **Calculation of seismic inertial loads on gravity dams vibrating in three dimensions** (Seismicheskaya inertsionnaya nagruzka na plotinu gravitatsionnogo tipa, vychislennaya s uchetom ee prostranstvennykh kolebanii, in Russian), *Seismostoikost sooruzhenii, 3,* 1974, 124–133.

A technique is presented for calculating the free vibration modes and frequencies of, and inertial loads on, two types of dams: gravity dams and trapezoidal earth dams adjacent to a canyon of the same shape. The dam is regarded as a series of plates of constant cross section under plane stress (for the case of vertical vibrations and those perpendicular to the canyon). When the vibrations along the canyon are calculated, the plane element is regarded as a plate subjected to bending.

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5.4-20 Atrakhova, T. S., **On design of earth dams for seismic loads** (O raschete zemlyanykh plotin na seismicheskie vozdeistviya, in Russian), *Seismostoikost bolshikh plotin,* 1973, 100–103.

The response of an earth dam is calculated using the finite element method. Within the limits of admissible errors, the effects of variations in initial data on the resulting mode shapes and natural frequencies of the dam are analyzed.

5.4-21 Mamradze, G. P. and Dzhindzhikhashvili, G. Ya., **On calculating porous water pressure in saturated soils under seismic conditions** (K otsenke porovogo davleniya vody v vodonasyshchennom grunte v seismicheskikh usloviyakh, in Russian), *Soobshcheniya Akademii Nauk Gruzinskoi SSR,* 2, 1974, 405–408.

Earthquake resistance of saturated soils and structures (such as earth dams and embankments) regarded as a two-phase solid-liquid system is calculated. The solution takes into account the compressibility of water. The case of horizontal vibrations in a rectangular region bounded by impermeable walls and bottom is considered. Analysis of the solution obtained shows dynamic water pressures in porous media substantially higher than those in soil layers of the same height.

● 5.4-22 Uezawa, H., **Subsidence of embankment on weak ground due to earthquake and its countermeasure,** *Quarterly Reports, Railway Technical Research Institute,* **16**, 3, Sept. 1975, 103–106.

Embankments on weak ground subside significantly on the occasion of an earthquake. Estimation of the subsidence of an embankment is described from the viewpoint of liquefaction at the bottom of the embankment and the lateral flow of the ground. Effects of various countermeasures against subsidence caused by earthquakes are examined from the speed of subsidence in an experimental embankment. The countermeasures are effective for ground with limited strength. The necessary height of side fill and the seismic force acting on the countermeasure with a tension member also are described.

5.5 Dynamic Behavior of Foundations, Piles and Retaining Walls

● 5.5-1 Reese, L. C. and Welch, R. C., **Lateral loading of deep foundations in stiff clay,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT7,* Proc. Paper 11456, July 1975, 633–649.

A full-sized drilled shaft, or drilled pier, was constructed in the field in a stratum of stiff clay. The foundation was instrumented so that bending moment could be measured at various depths. A series of lateral loads, both short-term static and cyclic, were applied to the foundation and families of bending moment curves, along with the boundary conditions at the groundline, were obtained. These data were analyzed and sets of curves were developed showing soil resistance p as a function of deflection y for various depths. Rational concepts concerning the behavior of soil around a laterally loaded deep foundation were employed, along with some empirical expressions. Equations are presented for the development of p-y curves for stiff clay, both for short-term static loading and for cyclic loading. The expressions were tested against available experiments and were found to yield satisfactory results.

5.5-2 Shestoperov, G. S. and Klimova, L. P., **The SEINA-74 computer program for calculation of seismic loads** (Programma dlya opredeleniya seismicheskikh nagruzok SEINA-74, in Russian), *Sbornik nauchnykh trudov VNII transportnogo stroitelstva, 67,* 1975, 88–106.

The algorithm for the calculation of seismic loads realized in the SEINA-74 program is presented. Examples of the uses of the program in studies of various structures, including bridge piers, are given.

● 5.5-3 Poulos, H. G., **Lateral load-deflection prediction for pile groups,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT1,* Proc. Paper 11061, Jan. 1975, 19–34.

A simple method of predicting the load-deflection behavior of a laterally loaded pile group is developed by combining a nonlinear load-deflection analysis for a single pile with an elastic analysis of pile groups. The parameters most influencing the prediction are the soil modulus and the ultimate lateral load of a pile in the group, H_u. The soil modulus may be backfigured from a lateral load test on a single pile, and a method of interpretation of the test is described. The lateral load capacity of an isolated single pile also may be estimated, and by multiplying this value by a lateral group efficiency factor, H_{ur} may be determined. A number of comparisons between the observed and predicted load-deflection behavior of model pile groups show good agreement and suggest that the proposed method is capable of providing satisfactory load-deflection predictions for laterally loaded pile groups, provided appropriate values of soil modulus and H_{ur} can be input into the analysis.

● 5.5-4 Anderson, G. L., **The influence of rotatory inertia, tip mass, and damping on the stability of a cantilever beam on an elastic foundation,** *Journal of Sound and Vibration,* **43**, 3, Dec. 8, 1975, 543–552.

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The stability of a uniform viscoelastic cantilever resting on an elastic foundation, carrying a tip mass, and subjected to a follower force at its free end is investigated. The effects of the rotatory inertia of the beam, the transverse and rotatory inertias of the tip mass, and the foundation modulus, which characterizes a Winkler-type elastic foundation, are included in the partial differential equation of motion and boundary conditions, and the influence of these quantities on the value of the critical flutter load parameter Q_f is sought. The exact forms of the fundamental frequency equations are derived for the cases of a viscoelastic and a purely elastic beam, and these equations are solved numerically for Q_f. These numerical results reveal that Q_f depends strongly upon the foundation modulus for the cantilever carrying a tip mass or possessing rather small internal damping. In the absence of damping and a tip mass, the value of Q_f, computed upon the inclusion of the rotatory inertia of the beam in the formulation of the equation of motion, is decreased slightly and continues to decrease in essentially a linear manner as the value of the foundation modulus parameter κ is decreased. Moreover, when the effect of very small internal damping is included, the value of Q_f computed when the rotatory inertia of the beam is neglected increases slowly in an essentially linear fashion as κ increases, whereas, when the effect of rotatory inertia is retained, the value of Q_f decreases as κ is increased. Additional numerical results are reported graphically.

● **5.5-5** Kameswara Rao, N. S. V., Das, Y. C. and Anandakrishnan, M., **Dynamic response of beams on generalised elastic foundations,** *International Journal of Solids and Structures,* 11, *3,* Mar. 1975, 255–273.

Dynamic responses of beams on generalized elastic foundations are studied using the method of initial parameters. The foundation model proposed by Vlasov and Leontev is modified by incorporating into the analysis the horizontal displacements in the elastic foundation, thus making it more general and physically realistic. Results are compared with those reported by Rades, using Pasternak's foundation model and Winkler's model. The insufficiency of the Winkler model for the study of dynamic responses (mainly the bending moments) is emphasized. General solutions are presented for application to beams on generalized elastic foundations subjected to arbitrary external dynamic loads and/or moments.

● **5.5-6** Distefano, N. and Todeschini, R., **A quasilinearization approach to the solution of elastic beams on nonlinear foundations,** *International Journal of Solids and Structures,* 11, *1,* Jan. 1975, 89–97.

In this paper, the solution of a beam on a nonlinear elastic foundation, the deflection of which satisfies the nonlinear boundary value problem, is studied by means of the theory of quasilinearization. The problem is formulated in Section 2 where conditions for the existence and uniqueness of the solution are stated. In Section 3, the idea of quasilinearization is introduced and the positivity of an associated linear differential operator is investigated. In Section 4 the usual version of quasilinearization, i.e. the Newton-Raphson-Kantorovich sequence, is presented and conditions under which this sequence is monotonically convergent are established. In Section 5, an alternative successive approximation scheme, the derivation of which relies on ideas of quasilinearization, is presented. Finally, an example is solved by numerical procedures based on the methods discussed in previous sections.

● **5.5-7** Ilijichev, V. A. and Mongolov, Yu. V., **On calculation of pile foundation under seismic load,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 2, Nov. 1974, 43–45.

The paper briefly describes a method for evaluating the bearing capacity of a pile foundation in seismic regions. The natural frequency of the pile-soil system is shown to be relatively unimportant for this. However, considering the seismic intensity, the authors have taken into account the influence of the seismic vibrations on the change of soil properties. Expressions, based on the theory of beams on elastic foundations, are derived to obtain the maximum bending moment and maximum shear force in the pile and the maximum soil reaction as a function of pile length, cross section of the pile and soil conditions.

● **5.5-8** Ranjan, G. and Bhargava, S., **Earth pressure coefficients for ultimate lateral resistance of laterally loaded vertical piles,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 213–218.

Piles have been used successfully in many situations to resist lateral loads, caused by earth or water pressure, or by wind or seismic forces. The increase in the size of such structures and their increased use in offshore activity have brought about the need for more accurate knowledge of the behavior of laterally loaded piles.

Attempts have been made in the past to analyze laterally loaded rigid vertical piles, using earth-pressure coefficients. Since earth-pressure coefficients depend significantly upon pile roughness, different coefficients should be used to estimate the ultimate resistance of piles of different materials. In view of this, the equation for earth-pressure coefficients, developed earlier by Meyerhof and Ranjan, was modified and solved for surfaces varying from smooth to rough. A computer program was written. The results are presented in the form of graphs, which can be used for direct calculation of the ultimate resistance of rigid piles under horizontal loads.

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Using these earth-pressure coefficients, the authors estimate the ultimate resistance of piles and compare the results with the reported experimental results. The variation between the theoretical estimates and the experimental results and conclusions arising out of the study are discussed.

● 5.5-9 Reese, L. C., Cox, W. R. and Koop, F. D., **Analysis of laterally loaded piles in sand,** *Preprints, 1974 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2080, May 1974, 473–483.

Data were taken during the lateral loading of two 24-in. diameter test piles installed at a site where the soils consisted of clean fine sand to silty fine sand. Two types of loading were employed, static loading and cyclic loading. The data were analyzed and families of curves were developed which showed the soil behavior presented in terms of the soil resistance p as a function of pile deflection y.

With theoretical studies as a basis, a method was devised for predicting the family of p-y curves based on the properties of sand and pile dimensions. Procedures are suggested for both static loading and cyclic loading. While there is some basis for the methods from theory, the behavior of sand around a laterally loaded pile does not yield to a completely rational analysis; therefore, a considerable amount of empiricism is involved in the recommendations.

The procedure was employed for predicting p-y curves at the experimental site, and computed results are compared with experimental results. The agreement is good.

● 5.5-10 Luco, J. E., Wong, H. L. and Trifunac, M. D., **A note on the dynamic response of rigid embedded foundations,** *International Journal of Earthquake Engineering and Structural Dynamics,* 4, 2, Oct.–Dec. 1975, 119–127.

The problem of the dynamic response of rigid embedded foundations subjected to the action of external forces and seismic excitation is analyzed. It is shown that to calculate the response of rigid embedded foundations, or the response of flat rigid foundations subjected to nonvertically incident seismic waves, it is necessary to obtain not only the impedance matrix for the foundation, but also the forces induced by the incident seismic waves. Under these general conditions, rocking and torsional motion of the foundation is generated in addition to translation. The case of a two-dimensional rigid foundation of semi-elliptical cross section is used as an example to illustrate the effects of the embedment depth and angle of incidence of the seismic waves on the response of the foundation.

● 5.5-11 Kuribayashi, E., Iwasaki, T. and Kawashima, K., **Dynamic behaviour of a subsurface tubular structure,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 171–180.

A new seismic-resistant design criterion, seismic deformation analysis, is proposed. The criterion is based on wave propagation principles and thus avoids the force method principles of the seismic coefficient method.

Subsurface ground conditions, such as density, elastic moduli and thickness, provide the natural period of the subground. Displacements of the subsurface ground at specific sites are obtained given input accelerations, bedrock properties, and damping ratios. The deformations and working stresses of the structural systems of a tunnel, assumed to be an embedded beam or rod supported elastically by the soil, are evaluated by sweeping values of the wavelengths, providing maximum stresses at a respective point of the tunnel structure. In addition, the interpretation of effects on the deformations and stresses caused by geological and geodetic variation of the site and boundary conditions of the structural systems is discussed. As an example, the method is applied to a proposed submerged tunnel across Tokyo Bay.

● 5.5-12 Englehardt, K. and Golding, H. C., **Field testing to evaluate stone column performance in a seismic area,** *Géotechnique,* **XXV**, *1,* Mar. 1975, 61–69.

For construction of a 16 mgd sewage treatment plant on predominantly deep, soft, cohesive soils in an area of highest seismic susceptibility, soil improvement with stone columns was considered as one foundation solution. While the deformation behavior of subsoil improved with stone columns under static vertical load has been documented, little if any information is available on the performance of such improved soils under seismic loading conditions. For this reason, large-scale field tests were performed to demonstrate that (a) in the process of stone column installation, sand lenses in the predominantly cohesive subsoil are sufficiently densified with respect to liquefaction potential; (b) the combined mass of stone columns and native, intervening soil develops sufficient shear strength to resist safely horizontal forces resulting from a ground acceleration of 0.25 g; (c) the stone column pattern which satisfied the shear and density requirements also provides an adequate load-settlement relationship.

● 5.5-13 Reddy, A. S. and Ramasamy, G., **Analysis of tapered piles with axial and lateral loads,** *The Journal of the Institution of Engineers (India),* **54**, *CI 5,* May 1974, 188–191.

This paper presents an analysis for an individual tapered pile embedded in cohesive soil and subjected to

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axial and lateral loads, taking into account the yielding of the soil near the ground surface. The differential equations governing the pile deflection in plastic and elastic regions are solved and solutions are presented in nondimensional form. Results obtained using a computer program are presented and discussed to show the influence of taper, axial load, plastic resistance of soil and end conditions.

● 5.5-14 Wedpathak, A. V. *et al.*, **Vibrations of block type machine foundations due to impact loads,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 219–226.

Prototype vibration studies were carried out on malfunctioning forge hammer foundations, as well as on foundations working satisfactorily. Comparative quantitative assessments were made. The ratio of vibration intensity measured at anvil to that at the foundation was utilized to assess the efficiency of a Korfund vibration-absorbing pad and to assess its effect on foundation vibrations. It was observed that vibration intensities at the anvils of all the forge hammers studied were within the permissible limit of 3 to 4 mm, while the intensities at the foundations were within 1.0 to 1.2 mm, as suggested by Barkan—except in one case where the foundation was also reported to be malfunctioning, the intensity was of the order of 1.65 to 2.1 mm. The vibration intensity ratios obtained were above 2.5, indicating the good condition of the vibration-absorbing Korfund pads, which reduced the vibration intensity at the foundations. In the case of foundation malfunctioning, the vibration intensity ratio was almost 1.1. This showed practically no absorption of vibration intensity by the Korfund pad, resulting in large vibrations in the foundation which were accompanied by the observed sinking and tilting.

The results of theoretical analyses reveal that the amplitudes of anvil vibrations are comparable to those experimentally obtained, whereas the amplitudes of foundation vibrations are much smaller than the experimentally obtained ones. The theoretical analysis, in general, showed that all the foundations satisfied the conditions of their dynamic stability within the limits of various assumptions involved in the analysis.

● 5.5-15 Stokoe, II, K. H. and Erden, S. M., **Torsional response of embedded circular foundations,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 42, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

An experimental investigation of the influence of embedment on the natural frequency and the damping ratio of circular foundations subjected to torsional excitation is presented. Concrete model footings were used. Embedment ratios ranged from 0.0 to 1.24. Three different embedment conditions were studied: cast-in-place embedment, embedment in backfill, and embedment with no soil contact along the embedded side. The largest increase in the natural frequency and the damping ratio occurred for cast-in-place embedment. Very little change in the natural frequency and the damping ratio occurred for embedment with no side contact. In general, embedment effects decreased as the mass ratio increased.

● 5.5-16 Petrovski, J. and Jurukovski, D., **Static and dynamic test of piles under horizontal load,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 55, 9. (For a full bibliographic citation see Abstract No. 1.2-8.)

In order to predict the dynamic response of a twenty-two story large panel prefabricated building supported by a pile foundation, static and dynamic tests on a single pile and a group of four piles were performed. Using the experimental results, the soil-pile interaction parameters have been evaluated and applied to the mathematical model formulation of the structural system considered.

● 5.5-17 Mirza, W. H., **Vibration of soil-supported foundations,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 56, 8. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper describes the experimental as well as theoretical study of soil-supported foundations. Dimensionless ratios based on the transfer matrix technique have been obtained for modelling the soil-structure system to study the dynamic behavior experimentally. Vibration characteristics of an equivalent model of a massive machine foundation have been determined in the laboratory. Theoretical investigations, based on transfer matrix techniques, the lumped parameter approach and finite element methods also are discussed, and a comparison is made with the experimental work.

5.5-18 Mochizuki, T., **Some considerations on the horizontal restoring force acting on the pile** (in Japanese), *Transactions of the Architectural Institute of Japan, 233,* July 1975, 51–60.

This paper describes the hysteretic force-deflection relation for a pile foundation. The pile is assumed to be a one-degree-of-freedom system.

The alpha value of the force-deflection relation changed as a result of a lateral loading test conducted at various depths of a layer of loam. The value near the ground surface was lower than the value at a deeper depth.

A reinforced concrete pile, free at the top and embedded in the loam layer, was examined. After yielding, the alpha value of the pile was nearly equal to the value near the ground surface. However, there was no difference in

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

the initial alpha values in these two cases. Equations are presented for obtaining hysteresis curves, equivalent viscous damping constants and steady-state response curves.

5.5-19 Matsushima, Y., **Spectra of spatially variant ground motions and associated transfer functions of soil-foundation system** (in Japanese), *Transactions of the Architectural Institute of Japan, 232*, June 1975, 63–69.

Because of the possibility of spatial variation, ground surface movements during an earthquake are not necessarily identical, even in a relatively limited plane. In this paper, mathematical expressions of cross-spectral density functions of such ground motions are investigated, and associated transfer functions of soil-foundation systems are derived.

Some past earthquake observations of building foundations and ground surfaces are reviewed. A technique is described by which the response of rigid foundations due to multiple inputs is evaluated in a frequency domain using probabilistic theory. The cross-spectral density functions of statistically correlated ground motions are expressed in mathematical form, together with corresponding transfer functions of soil-foundation systems obtained by the method discussed. The results are compared with the observations. In addition, ground motions with phase differences are discussed.

5.6 Experimental Investigations

● 5.6-1 Woods, R. D., Barnett, N. E. and Sagesser, R., **Holography—A new tool for soil dynamics**, *Journal of the Geotechnical Engineering Division, ASCE*, **100**, *GT11*, Proc. Paper 10949, Nov. 1974, 1231–1247.

Holographic interferometry was used to find dynamic displacement of the surface of a sand halfspace model excited by a harmonically vibrating circular footing. The screening effectiveness of wave barriers composed of rows of vertical cylindrical holes was studied using this technique. The general results indicate that: (1) holographic interferometry is a powerful tool for measurement of static as well as dynamic displacement of the surface of a sand halfspace model; and (2) stroboscopic, double exposure, holographic interferometry can be used to get "stopped motion" records of traveling waves. Specific results for barriers indicate that the scaled hole diameter (diameter/wavelength of Rayleigh wave) should be at least 1/6, the net scaled spacing [(c-c spacing - diameter)/wavelength] should be less than 1/4, and the solid-filled hole barriers behave fundamentally differently than fluid-filled or void holes.

5.6-2 Kudrya, V. I., **On shear resistance of soils under dynamic loads** (O soprotivlenii sdvigu gruntov pri dinamicheskikh vozdeistviyakh, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 87*, 1973, 32–35.

Results of experimental laboratory studies aimed at determining shear resistance of soils are presented. The possible uses of elastic-plastic soil models in earthquake-resistant design of rigid structures are explored.

● 5.6-3 Brown, S. F., **Repeated load testing of a granular material**, *Journal of the Geotechnical Engineering Division, ASCE*, **100**, *GT7*, Proc. Paper 10684, July 1974, 825–841.

Both the resilient and permanent strains were measured and shown to reach equilibrium values after some 10^4 stress cycles under drained test conditions. The effect of changes in both the mean level and the amplitude of the deviator stress were studied and samples were tested at various constant cell pressures. The measured strains were shown to be dependent on the applied stress conditions expressed as dynamic deviator stress, mean normal stress, and cell pressure. The well-known nonlinearity between stress and resilient strain was noted and quantified for this particular material. The simple relationship previously established between resilient modulus and either cell pressure or the sum of the principal stresses was investigated and found to apply only under specific circumstances. More generally, resilient modulus depended on both the normal and shear stress conditions.

● 5.6-4 Silver, M. L. and Park, T. K., **Testing procedure effects on dynamic soil behavior**, *Journal of the Geotechnical Engineering Division, ASCE*, **101**, *GT10*, Proc. Paper 11671, Oct. 1975, 1061–1083.

Cyclic triaxial tests were performed on dry and saturated undrained sands using stage testing methods to investigate the influence of repeated cyclic straining and specimen reconsolidation on equivalent linear modulus and damping values on both a total stress and on an effective stress basis. It was found that: (1) modulus and damping values for dry sand are not significantly affected by stage testing; (2) damping values are not significantly higher for saturated specimens than for dry specimens; (3) volume changes in saturated specimens induced by stage testing can be severe and can severely change initial testing densities; and (4) modulus values for saturated sands are significantly higher for stage tested specimens than for fresh specimens at the same shear strain levels after the same number of cycles. It was concluded that stage testing methods may not give reasonable values of dynamic soil properties for saturated undrained sands for shear strain levels greater than about 0.1% or for more than about 25 strain cycles.

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● **5.6-5** Toki, S. and Kitago, S., **Strength characteristics of dry sand subjected to repeated loading,** *Soils and Foundations,* **14,** *3,* Sept. 1974, 25–39.

Some results of research on the strength of dry sand are presented. These results are based on experiments carried out over a period of several years on the geotechnical properties of dry sand subjected to repeated loading. Investigated were the dependency of the dynamic strength of sand on the number of cyclic loadings, the static stress state of sand prior to the application of cyclic stress, the initial and failure void ratios of the sand, etc. Comparisons also were made between the dynamic strength and the static strength. The test results indicate that dry sand shows a higher strength against dynamic loading than against static loading but in view of deformation sand is less stable against repeated loading.

● **5.6-6** Tatsuoka, F. and Ishihara, K., **Drained deformation of sand under cyclic stresses reversing direction,** *Soils and Foundations,* **14,** *3,* Sept. 1974, 51–65.

A series of cyclic triaxial tests with varying amplitude was performed on samples of a sand. The samples were subjected to stress reversal from compression to extension and vice versa. The effect that the previous stress history in triaxial extension might have on the current deformation characteristics in triaxial compression, and vice versa, was investigated. It was found that yielding of sand in reversing stress condition could occur independently of the previous stress history in an opposite direction, as long as the stress amplitude was made to stay within some limit. On the basis of the directional independency indicated above and the knowledge concerning the deformation characteristics under monotonous loads, an attempt was made to assess how dilatancy and shear strains develop progressively during cyclic loading. This method proved to be applicable not only for stress-controlled but also for strain-controlled performance of sand.

● **5.6-7** Tatsuoka, F. and Ishihara, K., **Yielding of sand in triaxial compression,** *Soils and Foundations,* **14,** *2,* June 1974, 63–76.

By employing different kinds of stress paths, drained triaxial compression tests were conducted on sand samples having several densities. In the course of complicated cycles of stress change, the states of stress at which plastic deformations begin to take place were determined. Using a number of plastic yield points, the simple analysis obtained permitted families of yield loci to be established in the stress space, depending upon the densities of the sand samples used. The proposed form of yield loci is compared with the similar loci suggested by Schofield and Wroth and Poorooshasb, and coincidence or difference between these loci is examined in the light of the results of tests specially performed for this purpose.

● **5.6-8** Prakash, S., Nandakumaran, P. and Bansal, V. K., **Behaviour of soil under oscillatory shear stresses,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 127–134.

The behavior of three artificial c–ϕ soils under oscillatory shear stresses is studied. The effects of various parameters on the strength characteristics of the soils are taken into account. The parameters studied include frequency of load application, number of cycles, normal stress, pulsating shear stresses and type of soil. It is found that (i) The strength of soil is reduced in dynamic tests. (ii) The reduction in strength is only for the cohesion parameter; the friction parameter remains the same in static as well as in dynamic tests. (iii) The larger the frequency of the dynamic load, the larger the reduction in strength is in the tested range of 0.175 Hz to 0.7 Hz. (iv) Under dynamic testing, there is more of a percentage reduction in strength for compressible soil than there is for silty sand.

● **5.6-9** Kumbasar, V. and Erguvanli, A., **Behaviour of dry sand slopes under seismic shaking conditions,** Dept. of Geotechnical Engineering, Istanbul Technical Univ., Istanbul, 1974, 18.

Shaking table tests of varying intensities were conducted on two types of dry sand slope models. The variations in the change of the slope angles and the critical acceleration values causing instability at different angles were determined. In general, the angles decreased with increasing acceleration ratios. Behavior change occurred as a result of the different boundary conditions of the two slope types. Further research is needed for comparison of these results with the results of analytical studies.

● **5.6-10** Erguvanli, A., **Model tests on a small shaking table,** Dept. of Geotechnical Engineering, Istanbul Technical Univ., Istanbul, 1974, 18.

Shaking table tests were conducted on noncohesive sand layers subjected to sinusoidal vibrations. The sand was analyzed both for volumetric changes and for liquefaction potential. The results clearly demonstrate the effects of the void ratio (relative density) and the acceleration level (intensity of shaking) on the behavior of the sand. The volumetric changes measured were in agreement with analytical results. The authors conclude that further research should consider the effects of other variables, such as surcharge pressure and the duration of shaking. An appendix covering the principles of model similitude and model testing is included.

● **5.6-11** Kuribayashi, E., Iwasaki, T. and Tatsuoka, F., **Stress condition effects on dynamic properties of soils,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 135–144.

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Laboratory tests, using the resonant column method, were conducted to evaluate the shear modulus and the damping characteristics of dry and saturated specimens of variable soils. The hollow cylindrical samples tested were 25 cm in height, 10 cm in outside diameter and 6 cm in inside diameter. The specimens were fixed at the bottom and the oscillators were fastened to the rigid mass on the top of the specimens. The confining pressure was supplied by air pressure, and the axial load was applied independently of the confining pressure to produce the anisotropic stress conditions. The frequency of the torsional excitation was varied until the oscillator-specimen system resonated in testing. The strain amplitude varied from 5×10^{-6} to 5×10^{-4} in these tests. The shear moduli were calculated from the resonant frequencies and other parameters as above. The damping characteristics were obtained by the amplitude-time decays in the free vibrations.

Test results show the following: (1) Under constant values of other parameters, shear moduli vary with 1/2 power of the mean principal stress, p, and decrease with an increase of void ratios and shearing strain amplitudes. Furthermore, damping capacities decrease with increase of p and increase with increase of strain amplitude. However, damping capacities take constant values irrespective of change of void ratios under constant values of other parameters. (2) While the value of p is kept constant, the shear modulus is nearly constant irrespective of the value of the deviator stress, q, until the stress ratio, q/p, reaches some value, say 1.0. However, beyond this value of q/p, shear moduli begin to decrease with increase of q/p. This phenomenon is due to the anisotropic stress condition and the corresponding anisotropy in the inner structure of the specimens.

● 5.6-12 Gupta, Y. P., **Liquefaction studies of large saturated sand samples excited on a shaking table,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 145–150.

Liquefaction studies of large saturated sand samples 180 cm long, 45 cm wide and 18 cm high were conducted on a shaking table. Effects of variation in acceleration amplitude, frequency of vibration and waveform of base excitation were studied. In particular, the behavior during first and second liquefaction was watched carefully. Physical movement of the sand also was observed from a viewing window.

● 5.6-13 Cox, W. R., Reese, L. C. and Grubbs, B. R., **Field testing of laterally loaded piles in sand,** *Preprints, 1974 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2079, May 1974, 459–472.

A series of field tests was made to develop criteria for the design of laterally loaded piles in sand under both static and cyclic loads. Two 24-in. diameter piles were instrumented with strain gages for measuring bending moment at points along the piles. The gages were calibrated by applying known moments and reading the output of the gages. Hydraulic equipment was developed for applying both static and cyclic loads. A calibrated load cell, employing strain gages, was used for measuring lateral load, and linear-displacement transducers were used for measuring the deflection of the pile at two points above the ground surface. The output from the moment gages, from the load cell, and from the linear-displacement transducers was recorded with a high-speed digital system.

A site was selected at Mustang Island, Texas, and two soil borings were taken. The instrumented piles, the reaction piles, and the loading apparatus were installed, and a comprehensive series of field tests was performed. This paper describes the field testing of the two piles.

● 5.6-14 Park, T. K. and Silver, M. L., **Dynamic triaxial and simple shear behavior of sand,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT6,* Proc. Paper 11347, June 1975, 513–529.

The dynamic properties of dry sands from triaxial tests represented as values of modulus and damping were investigated and compared with simple shear test results for the same material using equivalent test parameters. It was confirmed that for both types of tests the effects of strain amplitude, relative density, and confining pressure are similar. Dynamic triaxial and simple shear modulus values can be related at the same shear strain amplitude and at equivalent confining pressures. A correlation curve is presented. The difference between triaxial and simple shear damping values is insignificant, and the results may be used interchangeably at equivalent shear strain amplitudes.

● 5.6-15 Castro, G., **Liquefaction and cyclic mobility of saturated sands,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT6,* Proc. Paper 11388, June 1975, 551–569.

Saturated sands subjected to earthquake loadings can develop two different phenomena, i.e., liquefaction and cyclic mobility. Liquefaction can develop only in loose sands and its mechanism is related to the critical state of the sand. Cyclic mobility can develop in any sand. The results of the cyclic triaxial tests used to study cyclic mobility are conservative for medium dense and dense sands, because of redistribution of water content in the specimens during the tests, application of axial extension loads, and loosening of the sand during sampling. To obtain an estimate of the conservatism of the cyclic triaxial tests, a comparision was made of the observed field behavior of saturated sands during earthquakes and of the results of cyclic triaxial tests on undisturbed samples.

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● **5.6-16** Wong, R. T., Seed, H. B. and Chan, C. K., **Cyclic loading liquefaction of gravelly soils,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT6*, Proc. Paper 11396, June 1975, 571–583.

The results of cyclic loading tests on gravelly soils using a 12-in. diameter triaxial test apparatus are described. The cyclic stresses required to cause ±2.5% and ±10% strain of saturated samples of gravelly soils are shown to be somewhat higher than those causing similar strains in sands. However, part of this increase may be due to the effects of membrane penetration and compliance in the test system. It is suggested that the superior field performance of gravelly soils over sands is probably due in large measure to the higher permeability of gravelly soils which will often permit sufficient drainage to occur to prevent the development of high pore-water pressures or liquefaction.

● **5.6-17** Reese, L. C., Cox, W. R. and Koop, F. D., **Field testing and analysis of laterally loaded piles in stiff clay,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2312, May 1975, 671–690.

Two nominally 24-in. diameter piles, instrumented for measuring bending moments, were driven into stiff clay and subjected to lateral loading. A nominally 6-in. diameter pile also was instrumented for measuring bending moments. It was driven at the same site, loaded, pulled, redriven and reloaded. Short-term static and cyclic loading was employed on both 24-in. diameter and 6-in. diameter piles. The water table was maintained a few inches above the ground surface during the testing program.

The results of the tests were analyzed to obtain families of curves showing soil resistance p as a function of pile deflection y. Based on the experimental p-y curves and on the theory for the behavior of soil, procedures for predicting p-y curves for stiff clay were developed. The procedures were used and predictions of pile behavior at the site were made. The predictions compared favorably with actual behavior.

● **5.6-18** Yoshimi, Y., Kuwabara, F. and Tokimatsu, K., **One-dimensional volume change characteristics of sands under very low confining stresses,** *Soils and Foundations,* **15**, *3*, Sept. 1975, 51–60.

One-dimensional compression and swelling tests were conducted on loose sands under very low confining stresses, including a liquefied condition. The vertical effective stresses from zero to 0.3kg/cm^2 were applied by means of vertical seepage through a column of sand 28 cm in diameter. Liquefaction of the specimens was caused by upward seepage or impact. The relationship between the void ratio and the logarithm of vertical effective stress during post-liquefaction compression was nearly linear over the stress range from 0.002kg/cm^2 to 0.2kg/cm^2. Even under a very low confining stress, the sand that had not undergone liquefaction was considerably less compressible than the sand that had been liquefied. The coefficient of volume change during unloading was around one-fifth of that during post-liquefaction compression for loose or very loose sand from Niigata. On the basis of the test results, the average vertical strain of a horizontal layer of sand during consolidation under its own weight following liquefaction was estimated to be of the order of a few per cent.

● **5.6-19** Yoshimi, Y. and Oh-Oka, H., **Influence of degree of shear stress reversal on the liquefaction potential of saturated sand,** *Soils and Foundations,* **15**, *3*, Sept. 1975, 27–40.

A series of dynamic cyclic shear tests under undrained conditions were conducted to determine the conditions for inducing liquefaction of saturated sands, using a ring torsion apparatus to apply cyclic shear stresses under nearly plane strain conditions. In addition to completely reversed cyclic tests, partially reversed and unreversed cyclic tests were performed by superposing static initial shear stress on dynamic shear stress pulses. Most specimens were of a relative density of approximately 40 per cent, and the frequency of the cyclic shear stress ranged from 1Hz to 12Hz.

Sudden failure of the specimens, which was clearly recognized in the completely reversed and partially reversed tests, was not observed in the unreversed tests. Irrespective of the degree of stress reversal, liquefaction failure became imminent when the ratio of the peak shear stress to the vertical effective stress reached a certain critical value. The degree of stress reversal had considerable effect on the conditions to cause initial liquefaction, but had no significant effect on the conditions to cause complete liquefaction. For competely reversed tests, the conditions to induce liquefaction were nearly independent of the frequency of the cyclic shear stress from 1Hz to 12Hz.

● **5.6-20** Ishihara, K. and Yasuda, S., **Sand liquefaction in hollow cylinder torsion under irregular excitation,** *Soils and Foundations,* **15**, *1*, Mar. 1975, 45–59.

Dynamic torsion shear tests on hollow cylindrical samples of saturated sand were conducted by incorporating the test apparatus into an electrohydraulic type loading system in which any desired form of load time history can be applied to the specimen. The acceleration records taken during recent major earthquakes were used as representative time histories in the test programs. For the several waveforms used, relationships were established between the amplitude of shear stress and the residual pore pressures. These relationships may be used to assess the dy-

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namic pore pressures under irregular loading conditions. Finally, the results of dynamic torsion shear tests were compared with the corresponding behavior in dynamic triaxial tests, and the correlation between them is discussed.

● 5.6-21 Brown, S. F., Lashine, A. K. F. and Hyde, A. F. L., **Repeated load triaxial testing of a silty clay,** *Géotechnique*, XXV, *1*, Mar. 1975, 95–114.

Repeated load triaxial tests have been carried out on samples of Keuper marl reconstituted from a slurry. The stress history of each sample was controlled and overconsolidation ratios between 2 and 20 were used. The repeated load tests were carried out undrained and involved the application of cyclic deviator stresses at a frequency of 10 Hz and the work was done in the context of the pavement design problem though the results may well be relevant to other situations such as those occurring beneath offshore gravity structures.

Measurements were made of both permanent and resilient strain and the mean value of pore pressure. It was shown that even after 10^6 cycles of stress, failure had not occurred in most of the samples although strains as high as 8% had developed in the more highly overconsolidated cases. Pore-pressures built up to constant positive values for lightly overconsolidated samples within about 10^4 cycles. For heavily overconsolidated samples, however, negative values were still building up in some cases even after 10^6 cycles. The results were compared with those obtained from conventional undrained strain controlled tests to failure.

While stress history was clearly an important parameter for permanent strain, resilient strain was shown to depend only on the applied stresses. The resilient modulus was shown to be a function of the cyclic deviator stress divided by the initial effective confining stress and this nonlinearity in the material was particularly marked at low values of this ratio.

● 5.6-22 Moussa, A. A., **Equivalent drained-undrained shearing resistance of sand to cylic simple shear loading,** *Géotechnique*, XXV, *3*, Sept. 1975, 485–494.

Medium dense and dense samples of clean sand prepared in the laboratory have been tested in Norwegian cyclic simple shear apparatus. The samples were subjected to different cyclic shear stresses under equivalent drained conditions followed by constant volume conditions. The effect of preshearing on the subsequent undrained shearing resistance of sand has been discussed. Also, the behavior of sand under cyclic simple shear loading was investigated.

● 5.6-23 Grib, S. I., **Behaviour of pile foundations under horizontal seismic action,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 53, 5. (For a full bibliographic citation see Abstract No. 1.2–8.)

Field tests were performed on pile foundations embedded in alluvial soil and subjected to horizontal seismic action using consecutive explosions. The pile top deflections, bending moments at pile sections and soil dynamic characteristics were measured in the tests. The test results for moments in the piles were compared to the analytical solution of the pile oscillation differential equation using the test data. From the study of pile behavior, confirmation of the design method within an acceptable degree of accuracy was obtained.

● 5.6-24 Kumbasar, V. and Erguvanli, A., **The damping characteristics of cohesive soils determined experimentally,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 18, 12. (For a full bibliographic citation see Abstract No. 1.2–8.)

The resonant column technique was the experimental approach used in the determination of the damping ratio of cohesive soils under small strain conditions. Experimental results establishing the effects of a plasticity index and the increase in the damping ratio with increasing water content and strain amplitude are included.

5.6-25 Kipiani, D. G., **Methods and results of field testing of stiffness of single floating pile foundations to obtain data for earthquake-resistant design** (Metodika i rezultaty polevogo issledovaniya zhestkosti fundamentov iz odinochnykh svai visyachego tipa v tselyakh polucheniya dannykh dlya rascheta ikh na seismicheskie vozdeistviya, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 106–117.

Tests of single piles under static and harmonic loading in horizontal and vertical directions were performed. A specially constructed platform consisting of a frame, two cross-shaped elements and a loading plate with a carrying capacity of 80 tons was used to apply loads to the piles. Free horizontal vibrations were measured at a load of 7 tons.

Data on the effects of horizontal deflection on the logarithmic decrement of horizontal vibrations at the top of the pile are presented. Stiffness in the horizontal direction varies widely indicating nonlinear deformations in the initial phases of loading.

5.6-26 Mochizuki, T., **On line real time dynamic test for the building supported on piles—Part 1: About the test method and restoring force characteristics of pile in cohesive soil** (in Japanese), *Transactions of the Architectural Institute of Japan, 231*, May 1975, 63–71.

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This paper describes the method of on-line real time dynamic tests for a building supported on piles and the results of tests of the restoring force characteristics of a pile model in cohesive soil. The principle of this method is coupling of a digital computer and the test apparatus. Using the restoring force between the soil and the pile from the test, the response of the building is generated by the computer in real time. The object of this investigation is to find the seismic effect of interaction between soil-pile, and pile-building on the entire system.

The results of dynamic tests on a pile model in clay, which are basic steps for a test on the entire system, are summarized as follows: (1) Hysteresis curves bear some resemblance to an ellipse or Jennings type. (2) Skeleton curves are expressed by the relation that force is proportional to the α power of the displacement where α is approximately 0.7 to 0.8. (3) The equivalent viscous damping constant is about 0.1 ~0.13, and its value does not increase with displacement. (4) It is found that the tensile-resisting force of soil still occurs at a considerably large displacement in this test, and the largest earth pressure takes place near the ground surface. (5) For extremely large displacements, a crevice will develop between soil and pile near the ground surface, and the maximum earth pressure arises near the middle depth. (6) The value of the lateral distribution of earth pressure at the side is about 2~3 times larger than it is at center.

● **5.6-27** De Alba, P., Chan, C. K. and Seed, H. B., **Determination of soil liquefaction characteristics by large-scale laboratory tests,** *EERC 75-14*, Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1975, 173.

The report describes a testing program to study the liquefaction characteristics of large (96" x 42" x 4") specimens of clean, saturated medium sand in cyclic simple shear conditions. Measurements of pore pressure and shear strain development are presented for sand specimens at relative densities of 54, 68, 82, and 90 per cent and the results interpreted to determine the values of stress ratio causing liquefaction at the various relative densities.

The effects of system volume change are examined, and appropriate corrections are made to the results. The corrected values are considered to be a very good approximation of the results that would be obtained from an ideal noncompliant testing system and free boundary effects.

The corrected test data are also compared with results obtained from small-scale test equipment and cyclic triaxial test and conclusions are drawn regarding the validity of the results obtained by these alternative procedures.

● **5.6-28** Seed, H. B., Arango, I. and Chan, C. K., **Evaluation of soil liquefaction potential during earthquakes,** *EERC 75-28*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1975, 113.

This report evaluates the results of a three-year research program conducted by the Univ. of California to investigate the settlement and liquefaction of sands under multidirectional shaking. This work represents a part of continuing studies to evaluate free-field soil behavior under earthquake loading conditions. This and other related studies each provide important steps in the overall project for improving methods for evaluation and prediction of soil behavior at potential nuclear power plant sites under seismic loading conditions.

6. Dynamics of Structures

6.1 General

6.1-1 Rasskazovskii, V. T., **Foundations of physical methods for calculating seismic response** (Osnovy fizicheskikh metodov opredeleniya seismicheskikh vozdeistvii, in Russian), FAN Publishers, Tashkent, 1973, 159.

Methods are outlined for calculating earthquake intensity using accelerograms. Problems in the mathematical modeling of damped structural vibrations are investigated. The design of structures is discussed for seismic loads computed from accelerograms based upon weight functions determined analytically and experimentally. Random factors are eliminated by means of models with a variable spectrum of natural frequencies and averaging over the set of possible values. A method for calculating regional seismic spectra is presented.

● 6.1-2 Atrakhova, T. S. and Grigoryan, E. B., **On the problem of picking the optimal number of concentrated parameters in dynamic analysis** (K voprosu o vybore optimalnogo chisla sosredotochennykh parametrov v dinamicheskikh raschetnykh skhemakh, in Russian), *Seismostoikost plotin, 3*, 1975, 144–155.

Results obtained by means of two different methods of dynamic analysis are compared in order to find the optimal method to determine the dynamic parameters with sufficient precision for engineering applications with the use of the least amount of computation.

● 6.1-3 Petrovski, J., Bouwkamp, J. G. and Jurukovski, D., **Cooperative research on full scale prefabricated buildings conducted by IZIIS, University Kiril & Metodij, Skopje and U. C. Berkeley**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 145, 5. (For a full bibliographic citation see Abstract No. 1.2–8.)

In an attempt to reduce the occurrence of catastrophic earthquake damage, and to provide better understanding of structural behavior under dynamic loads, an extensive five-year cooperative research project involving four research institutes in Yugoslavia and the Univ. of California, Berkeley, was initiated in 1971. Experimental studies are carried out by the Yugoslav participating institutions: IMK, Sarajevo; IGH, Zagreb; IMS, Belgrade; and IZIIS, Skopje. The Univ. of California, Berkeley, is charged with general project coordination, development of computer programs, and correlative studies to assess the accuracy of computer modeling techniques and analytical procedures.

A major part of this research program deals with the evaluation of the earthquake-resistant capabilities of three basically different types of building systems, constructed with industrialized methods. These studies involve both laboratory studies, carried out by the institutes in Sarajevo, Belgrade and Zagreb, and full-scale forced vibration studies on several buildings carried out by the Inst. of Earthquake Engineering and Engineering Seismology, IZIIS, Univ. "Kiril & Metodij," Skopje. The authors describe these forced vibration studies and report pertinent results.

● 6.1-4 Clough, R. W. and Penzien, J., **Dynamics of structures**, McGraw-Hill, Inc., New York, 1975, 634.

This book furnishes a comprehensive treatment of the theory of structural dynamics and its application to the solution of practical problems arising from the action of dynamic loads on structures. The methods described are applicable to any type of structure, including fixed civil engineering structures such as bridges or buildings, or vehicles such as airplanes or ships.

Presented in five parts, the book progresses in a logical sequence beginning with simple single-degree-of-freedom systems and advances to complex structures represented as

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discretized multidegree-of-freedom systems and elastic continua. Considered are the analysis of vibration mode shapes and frequencies, the response of structures to arbitrary periodic or nonperiodic loadings as well as both linear and nonlinear structures.

The topic of deterministic analysis theory and applications; by means of which the actual time variation of response to specified loading history may be evaluated, is the basis for the first three parts of the book. Part IV furthers the theme with a thorough and concise treatment of probability theory and the probabilistic approach to the analysis of dynamic response to random loadings. Dealing with earthquake engineering, Part V provides a compact coverage of the principal aspects of this subject, which is one of the most important applications of dynamics of structures.

6.2 Dynamic Properties of Materials and Structural Components

6.2-1 Chen, S. S. H. and Liu, T. M., **Extensional vibration of thin plates of various shapes,** *The Journal of the Acoustical Society of America,* 58, *4,* Oct. 1975, 828-831.

The problem of free extensional (in plane) vibration of thin plates of Hookean material of various shapes was studied. Solutions for dilatational and rotational vibrations were obtained separately. The boundary conditions were satisfied in a least-square sense. Numerical computations were performed for circular, elliptical, triangular, square, and hexagonal plates. The nodal pattern corresponding to each natural frequency for different modes was obtained. The frequency parameters computed for the circular plate are found to be within 0.05% of published results. For plates where known results were not available, the accuracy was checked by taking additional terms in the series solution and by dividing the boundary perimeter into finer intervals. It was found that the circular plate had the lowest fundamental frequency (k_1) at 2.049. The value increases as the shape is changed from a circle, with the triangular plate having the highest value at 6.733 in dilatational vibration while the frequencies in rotational vibration (h_1) were found to be 3.737 and 16.364, respectively.

6.2-2 Jones, E. R., Sierakowski, R. L. and Ross, C. A., **Damping measurements of a controlled composite material,** *The Journal of the Acoustical Society of America,* **57,** *6, Part II,* June 1975, 1465-1472.

Increased use of filamentary materials as reinforcements in structural components has necessitated obtaining information on the response of such material systems to a wide variety of loading conditions. One such technically important problem area is that associated with the dynamic response of composite materials to impact-type loading situations. In order to understand the phenomenon of wave travel in material systems, specific knowledge of the damping coefficient and phase velocity as a function of circular frequency is necessary. In the present paper, tests are reported for beam-type specimens of a steel-epoxy composite having controlled volume fractions and varying wire sizes. Measurements are reported on the damping coefficient as a function of circular frequency $a(\omega)$ and the real part of the complex modulus E_1. The latter parameter has been further used to calculate the phase velocity, and data are presented on phase velocity $c(\omega)$ as a function of frequency. Detailed tabular and graphical data are presented for the various specimens tested.

● 6.2-3 Khatua, T. P. and Cheung, Y. K., **Finite element analysis of multilayer sandwich plates and shells,** *Finite Element Methods in Engineering,* 161-176. (For a full bibliographic citation see Abstract No. 1.2-1.)

The study of conventional sandwich structures with two stiff layers separated by a weak core has been a topic of extensive investigation in the last few decades. However, sandwich structures with n stiff layers and n-1 alternating weak cores have been relatively unexplored by researchers. This is especially true of analysis using the finite element technique. In the investigation presented in this paper the assumption of common shear angle in all the core layers is not made. Arbitrary in-plane displacements are prescribed in all stiff layers resulting in a more rigorous analysis. A study is made of the bending and free vibration behavior of axisymmetric sandwich plates, cones and cylinders using the finite element method. A conical element is developed to solve these structures. Several standard problems are solved in order to test the extent of accuracy of the element.

● 6.2-4 Chen, W.-F. and Dahl-Jorgensen, E., **Polymer-impregnated concrete as a structural material,** *Magazine of Concrete Research,* **26,** *86,* Mar. 1974, 16-20.

Polymer-impregnated concrete (PIC), impregnated with the most often used polymers (polymethyl methacrylate and polystyrene), shows little ductility. The ultimate strength is often three to four times higher than that of ordinary concrete, but failure comes without warning in a brittle, almost explosive manner. This paper describes the results of an investigation designed to increase the ductility of PIC so that some plastic yielding can take place before and after the ultimate load is reached. Various percentages of monomer combinations of the methyl methacrylate were used with an elastomer, n-butyl-acrylate. The entire stress-strain relationship of the materials was determined by means of the splitting tensile and axial compression tests. The investigation shows that PIC can be modified to give either a material with high strength and little ductility or

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one with a somewhat lower strength and large ductility. Thus, potentially, material properties can be tailored to particular structural service requirements.

6.2-5 Rasband, S. N., **Resonant vibrations of free cylinders and disks,** *The Journal of the Acoustical Society of America,* **57,** *4,* Apr. 1975, 899-905.

A complete solution is obtained for nonaxisymmetric resonant vibrations of a free cylinder or disk involving infinite sums. For axisymmetric longitudinal vibrations, an alternative to previous solutions is included. In principle, the solutions satisfy exactly the stress-free boundary conditions, in contrast to the approximate bending-mode solutions due to Pickett or approximate solutions based on a small diameter/length ratio and small shearing stresses at the ends.

6.2-6 Sato, K., **Free flexural vibrations of an elliptical ring in its plane,** *The Journal of the Acoustical Society of America,* **57,** *1,* Jan. 1975, 113-115.

Free flexural vibrations in the plane of an elliptical ring of constant cross sections are studied. The present vibrations are considered in the elliptical coordinate system and the vibration displacements are expressed in terms of the series of Mathieu functions. The nondimensional eigenfrequencies calculated numerically are tabulated for various aspect ratios. The experimental results are obtained and are found to be in good agreement with the theoretical results.

6.2-7 Thomas, C. R., **Flexural and extensional vibrations of simply supported laminated rectangular plates,** *The Journal of the Acoustical Society of America,* **57,** *3,* Mar. 1975, 655-659.

The author has previously derived an effective stiffness, velocity-corrected theory of laminated composite plates based upon a microstructure plate theory developed by C. T. Sun. In this paper, the theory is used to study the flexural and extensional vibrations of simply supported rectangular plates; comparisons are made to similar results obtained from a reduced effective modulus or transversely isotropic plate theory. Free vibration frequency equations for simply supported edges are developed by passing solutions harmonic in both length and width through the differential equations while at the same time automatically satisfying the boundary conditions for simple supports. The variation of dimensionless frequency for such dimensionless variables is discussed and comparisons are made of the effective stiffness and effective modulus frequency results.

6.2-8 Ryabov, A. F. and Raskazov, A. O., **On the theory of vibrations of laminated orthotropic plates with filling** (K teorii kolebanii mnogosloinykh ortotropnykh plastin s zapolnitelem, in Russian), *Sopvotivlenie materialov i teoriya sooruzhenii, 24,* 1974, 126-132.

Vibration equations and boundary conditions for laminated plates with n orthotropic layers and with the arrangement of layers assumed to be nonsymmetric are derived using variational methods. Layers of filling with weak shear resistance are assumed present between plate layers. The arrangement of plate and filler layers is arbitrary. The plate layers have varying thicknesses and elastic properties. A system of equations is obtained which incorporates shear deformations for each layer as well as rotational inertia. The order of the system of equations is independent of the number of layers.

6.2-9 Monforton, G. R. and Ibrahim, I. M., **Analysis of sandwich plates with unbalanced cross-ply faces,** *International Journal of Mechanical Sciences,* **17,** *3,* Mar. 1975, 227-238.

The analysis of rectangular sandwich plates constructed of an orthotropic core and unbalanced cross-ply face plates is presented. A double Fourier series approach is used for simply supported sandwich plates under lateral loads. Results are compared to the corresponding sandwich plate results with orthotropic faces. The results indicate that the effect of bending-membrane coupling depends mainly upon the relative thicknesses of the core and faces; other factors include the shear stiffnesses of the core, the degree of anisotropy of the individual plies, the total number and lay-up of plies in the faces and the aspect ratio of the plate.

6.2-10 Beilin, E. A. and Kilimov, V. I., **Investigations of free flexural-torsional vibrations of thin beams under lateral parametric loads** (Issledovanie svobodnykh izgibnokrutilnykh kolebanii tonkostennykh sterzhnei, zagruzhennykh poperechnoi parametricheskoi nagruzkoi, in Russian), *Sbornik trudov Leningradskogo inzhenerno-stroitelnogo instituta, 105,* 1974, 46-58.

Natural frequencies are calculated of the flexural-torsional vibrations of rectangular thin beams subjected to lateral parametric forces, all in the same direction and constant in time. The effects on the natural frequencies of the location of the loading relative to the flexural axis and the degree of asymmetry in the beam cross section are investigated. In particular, it is established that, depending on the factors mentioned above, an increase in the magnitude of parametric forces in the initial stages of loading leads to an increase and not a decrease in the frequencies of flexural-torsional vibrations.

6.2-11 Sidikov, A. S., **Problems of free vibrations of laminated plates** (Nekotorie zadachi sobstvennykh kolebanii mnogosloinykh plastinok, in Russian), *Raschet prostranstvennykh stroitelnikh konstruktsii, 4,* 1974, 205-211.

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Free vibration frequencies of rectangular, freely supported laminated plates are calculated using the membrane analogy. The frequencies obtained are compared with the results of other authors' studies of laminated plates. The importance of restricting the validity of the formulas to plates with a ratio of length to thickness $l/h \geq 5$ is pointed out. The effects of variations in the Poisson coefficient of various layers and the arrangement of stiff and soft layers on natural frequencies are investigated. Graphs showing the relationship between relative plate thickness and natural frequencies are presented.

6.2-12 Rubin, C., **Vibrating modes for simply supported polar-orthotropic sector plates**, *The Journal of the Acoustical Society of America*, 58, *4*, Oct. 1975, 841-845.

A method is shown that will provide natural frequencies and mode shapes for the free vibrations of a simply supported polar orthotropic sectorial plate. The special case of a wedge-shaped plate also is treated. The solution applies to any sectorial plate with radial edges simply supported and arbitrary boundary conditions along the circular edges. A series solution which converges rapidly for many natural frequencies is obtained for radial, circular and mixed modes. An evaluation of the effect of plate orthotropy on the modes is presented. The solution is easily reduced to the isotropic case.

● 6.2-13 Salse, E. A. B., Ghosh, S. K., and Fintel, M., **Flexural properties of slender shear wall cross sections under monotonic loading**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 287-296.

The strength, stiffness and ductility of slender shear walls under combined gravity and lateral loads are considered. The results of an analytical study are presented in the form of design charts, with a design example included. The mathematical model used in this investigation simulates monotonic loading only, since no satisfactory model of the possible effects of cyclic loading on concrete behavior has been developed as yet.

● 6.2-14 Hanson, R. D., **Characteristics of steel members and connections**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 255-267.

The inelastic deformation behavior of a structure must be controlled in order to provide a stable building response. Several of the more important controls are (a) the structure should not lose strength during cyclic inelastic response, (b) the structural system should be capable of dissipating a significant amount of energy during cyclic motion, and (c) the structure should be capable of deformations several times those anticipated without failure or loss of strength and energy absorption capacity. This paper reviews the inelastic cyclic characteristics of steel members (specifically, beams, columns and bracing members) and connections so that they may be designed to provide the desired control mentioned above.

● 6.2-15 Hawkins, N. M., Mitchell, D. and Sheu, M. S., **Reversed cyclic loading behavior of reinforced concrete slab-column connections**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 306-315.

The effects are examined of reversed cyclic lateral loadings on the strength, stiffness, energy absorption and energy dissipation characteristics of five reinforced concrete slab-column connections without shear reinforcement and one with shear reinforcement. The measured strengths are compared with those of similar connections loaded monotonically to failure.

● 6.2-16 Kamat, M. P., **Effect of shear deformations and rotary inertia on optimum beam frequencies**, *International Journal for Numerical Methods in Engineering*, 9, *1*, 1975, 51-62.

The necessary condition for optimum fundamental frequency of a vibrating beam of constant volume and with a given distribution of nonstructural mass is obtained through the calculus of variations, accounting for shear deformations and rotary inertia effects. Minimum cross section of the beam is controlled by the introduction of an inequality constraint. A finite element displacement formulation is then used in an iterative manner to arrive at the optimum fundamental frequency and the corresponding material distribution for the discretized beam models with various boundary conditions. A comparison is then made with the corresponding result of a Euler beam.

6.2-17 Sridhar, S., Nayfeh, A. H. and Mook, D. T., **Nonlinear resonances in a class of multi-degree-of-freedom systems**, *The Journal of the Acoustical Society of America*, 58, *1*, July 1975, 113-123.

An analysis is presented of the superharmonic, subharmonic and combination resonances in a multidegree-of-freedom system that has cubic nonlinearity and modal viscous damping and is subjected to harmonic excitation. It is shown that, in the absence of internal resonances, the steady-state response contains only the modes which are directly excited. In the presence of internal resonances, it is shown that modes other than those directly excited can appear in the response. The strong influence of internal resonances is exhibited in numerical examples involving hinged-clamped beams. It is shown that when a multimode solution exists the lowest mode can dominate the response, even when it is not directly excited.

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6.2-18 Mattock, A. H., Johal, L. and Chow, H. C., **Shear transfer in reinforced concrete with moment or tension acting across the shear plane,** *Journal of the Prestressed Concrete Institute,* **20,** *4,* July-Aug. 1975, 76–93.

A comprehensive study of the shear transfer strength of reinforced concrete, subject to both single-direction and cyclic reversing loading (the latter simulating earthquake conditions), is currently in progress at the Univ. of Washington. This paper reports that part of the study is concerned with the effect of normal force and moment in the shear plane on single direction shear transfer strength.

Tests are reported of corbel type pushoff specimens and of pushoff specimens with tension acting across the shear plane. It was found that (1) moments in the shear plane less than or equal to the flexural ultimate moment of the shear plane do not reduce the shear transfer strength and (2) tension across the shear plane results in a reduction in shear transfer strength equal to that which would result from a reduction in the reinforcement parameter ρf_y by an amount equal to the tension stress.

Specific design recommendations are proposed. A future paper will extend the results of this investigation to lightweight concrete and provide a firm basis for corbel design.

● 6.2-19 Kunukkasseril, V. X. and Swamidas, A. S. J., **Vibration of continuous circular plates,** *International Journal of Solids and Structures,* **10,** *6,* June 1974, 603–619.

The general development of the theory given here considers the material to be orthotropic and continuous over $(n-1)$ elastic or rigid supports. The effect of rotatory inertia and in-plane loads also is included while formulating the equations of motion. Double and triple series solutions are given for orthotropic continuous plates. By matching the continuity conditions at the intermediate supports and satisfying the boundary conditions at the outer edge, the frequency determinant is obtained. For the purpose of numerical computations, an isotropic plate continuous over an intermediate-rigid or elastic-support and free and with no in-plane loads at the outer edge is considered. It is found that the influence of Poisson's ratio on the frequency parameter is significant only for the first symmetric or asymmetric modes. The rotatory inertia influences the frequency parameter when the radius-to-thickness ratio is less than 80, viz. when the plate is thick. Moreover, the elasticity of the support influences considerably the free vibration of plates.

6.2-20 Snowdon, J. C., **Moment impedance of internally damped rectangular and square plates with simply supported boundaries,** *The Journal of the Acoustical Society of America,* **57,** *5,* May 1975, 1108–1112.

Theoretical expressions for the moment impedances of simply supported, internally damped, rectangular and square plates are presented. The plates are driven either centrally or at an arbitrary point by a bending moment, the line of action of which has arbitrary direction. In calculations made to illustrate the frequency dependence of moment impedance, plate damping of the solid type has always been assumed. The expressions for moment impedance do not contain a logarithmic term that becomes infinitely large as the separation of the moment-producing pair of forces normal to the plate surfaces is reduced to zero. These expressions, therefore, contrast with prior expressions that have been derived for the moment impedance of infinite plates.

6.2-21 Dubenets, V. G. and Khilchevskii, V. V., **Effects of energy dissipation on dynamic behavior of structures subjected to plane stress** (Uchet rasseyaniya energii pri dinamicheskom raschete konstruktsii v usloviyakh ploskogo napryazhennogo sostoyaniya, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1,* 1975, 40–42.

The authors' equations expressing the relationship between stresses and deformations in the presence of complex stresses and energy dissipation are illustrated using the example of a rectangular plate. The method of dynamic analysis of thin homogeneous plates presented in the paper may be used for the evaluation of stresses from variable loadings and in design of homogeneous and nonhomogeneous laminated elements with strong damping properties.

6.2-22 Elishakoff, I., **Distribution of natural frequencies in certain structural elements,** *The Journal of the Acoustical Society of America,* **57,** *2,* Feb. 1975, 361–369.

The paper deals with the natural frequency distribution in beams, plates and shallow spherical shells. Expressions are found for the distribution functions (number of modes not exceeding a given cutoff level), for the integral approximations, and for the frequency derivatives of the latter—the so-called smeared modal densities. Special attention is paid to the singularities in these densities (present in certain elements), which were noted by Bolotin and which are referred to in literature as "condensation points." It is shown that omission of the concept of lowest natural frequency leads to a physical paradox and that the findings of most studies of modal densities should be revised. The method of integral approximations is applied to the problem of random vibrations of a shallow spherical viscoelastic panel. It is shown that the integral approximation of the averaged spectral density in the high-frequency range is equivalent to an infinite-system model. Moreover, it is shown that the physically inconsistent results reported in the literature regarding infinite discontinuities in the spectral densities of damped shells are erroneous and that they are due to the application to the low-frequency range of

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asymptotic expressions that are valid only at high frequencies.

● **6.2-23** Srinivasan, R. S. and Munaswamy, K., **Frequency analysis of skew orthotropic point supported plates,** *Journal of Sound and Vibration,* 39, 2, Mar. 22, 1975, 207–216.

In this paper free vibration analysis of skew orthotropic plates with point supports is accomplished by using higher degree skew finite strips. By applying small deflection theory, the expressions for strain energy and kinetic energy are derived. The displacement function for the strips is assumed as a series with polynomials in one direction and beam functions in the other direction. The boundary conditions at discrete point supports are incorporated as constraint equations. By solving these equations, the frequencies and mode shapes for different parameters are studied.

● **6.2-24** Swamidas, A. S. J. and Kunukkasseril, V. X., **Free vibration of elastically connected circular plate systems,** *Journal of Sound and Vibration,* 39, 2, Mar. 22, 1975, 229–235.

In a previous paper, the authors have presented the solutions for the normal mode vibrations of an n plate system. In that paper the numerical results were limited to the frequencies and mode shapes of some representative models of double plate systems. In the present paper additional numerical results are presented to illustrate the various other features such as the influence of the thickness ratio and foundation stiffness on the frequencies. The omission of a normal mode of the free-fixed case in the previously published paper also is pointed out.

6.2-25 Rumerman, M. L., **Vibration and wave propagation in ribbed plates,** *The Journal of the Acoustical Society of America,* 57, 2, Feb. 1975, 370–373.

A formalism is presented for handling problems of wave propagation and forced vibration in ribbed plates. A general solution is obtained for the forced vibration of an infinite thin plate periodically stiffened by identical, uniform ribs. The ribs are idealized as parallel line attachments capable of exerting line forces and line moments upon the plate. The magnitudes of these forces and moments are related to the motion of the plate through the impedances of the ribs and plate. The assumption of an externally applied pressure excitation, which varies harmonically in time and in the plane of the plate, permits an explicit solution; the principle of superposition is then used to construct the solution to an arbitrary excitation. By setting the amplitude of the harmonic excitation equal to zero, an equation for the free modes of the ribbed plate is derived.

● **6.2-26** Soni, S. R. and Amba-Rao, C. L., **Axisymmetric vibrations of annular plates of variable thickness,** *Journal of Sound and Vibration,* 38, 4, Feb. 22, 1975, 465–473.

Free axisymmetric vibrations of annular plates of variable thickness have been studied on the basis of the classical theory of plates. The Chebyshev collocation method has been employed to solve the differential equation governing the transverse motion of such plates. The displacement of the plate element is expressed as a Chebyshev polynomial in terms of the radial co-ordinate. As an example, frequencies and mode shapes have been computed for different values of taper constant and radii ratio for the first two modes of vibration of a plate with a linearly varying thickness.

● **6.2-27** Bickford, W. B. and Strom, B. T., **Vibration of plane curved beams,** *Journal of Sound and Vibration,* 39, 2, Mar. 22, 1975, 135–146.

An exact solution is obtained for the small amplitude motion of a plane constant curvature prismatic bar with no initial twist. The effects of shear deformation, rotatory inertia, and extensionality are included. By using the solution for the constant curvature element, the state vector transfer matrix approach is shown to be a very effective tool for investigating the in-plane and out-of-plane frequencies of arbitrarily shaped plane bars.

● **6.2-28** Ahuja, R. and Duffield, R. C., **Parametric instability of variable cross-section beams resting on an elastic foundation,** *Journal of Sound and Vibration,* 39, 2, Mar. 22, 1975, 159–174.

This paper is concerned with the onset of parametric instability and the steady-state parametric response of a beam with variable cross-section resting on an elastic foundation. The problem is studied both theoretically and experimentally.

The theoretical and experimental results show close agreement both for the boundaries of the principal and second temporal regions of instability and the steady-state response within the principal instability region. The experimental and theoretical results reveal that the slope factor of a beam with a linear variable cross-section has a pronounced effect upon the boundaries of the principal instability region. The effect of the elastic foundation is to decrease the width of the instability regions and the amplitude of the parametric response.

● **6.2-29** Sugiyama, Y. and Kawagoe, H., **Vibration and stability of elastic columns under the combined action of uniformly distributed vertical and tangential forces,** *Journal of Sound and Vibration,* 38, 3, Feb. 8, 1975, 341–355.

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Vibration and stability of elastic columns subjected to uniformly distributed follower forces are investigated by means of the finite difference method for six typical cases of boundary conditions. A system of k finite difference equations is made of compact form by introducing the concept of a transfer matrix. The behavior of the eigenvalue curve is demonstrated in detail for various values of the nonconservative parameter of the applied force. Precise stability maps are obtained from the eigenvalue analysis, which determines the divergence and flutter limits.

● 6.2-30 Ramachandran, J., **Non-linear vibrations of circular plates with linearly varying thickness,** *Journal of Sound and Vibration,* 38, 2, Jan. 22, 1975, 225-232.

In this paper, the influence of large amplitudes on free flexural vibrations of circular plates with linearly varying thickness is analyzed. Berger's assumption is used to derive the basic governing equations. Galerkin's averaging procedure is used to reduce the original equation to a system of ordinary differential equations with time as the independent variable, the solution of which is obtained by using the Wegstein iteration technique. Some numerical results are given, with both clamped and simply-supported edge conditions being considered.

● 6.2-31 Thakkar, S. K. and Arya, A. S., **Free vibration characteristics of fixed arches,** *The Journal of the Institution of Engineers (India),* **55,** *Part CI 2,* Nov. 1974, 39-43.

Free vibration characteristics, namely natural periods and modes, of various shapes and sizes of arches fixed at the ends are discussed. A wide practical range of geometrical parameters such as rise-span ratio, ratio of span-to-radius of gyration at crown, form factor and shape factor are considered to determine the influence of them on periods and mode shapes. It is found that variations of rise-span ratio, form factor and shape of factor within practical ranges have more influence on first modes and less on higher modes. For all practical purposes, the period coefficient is directly proportional to the ratio of span-to-radius of gyration. The rise-span ratio affects the symmetric mode patterns to a greater extent than it affects the antisymmetric modes.

6.2-32 Becker, R., **Panel zone effect on the strength and stiffness of steel rigid frames,** *Engineering Journal, AISC,* **12,** *1,* 1975, 19-29.

The effect of the panel zone on the strength and stiffness of rigid steel frames is examined. The panel zone is the portion of the frame where the boundaries are within the rigid connection of two or more members that have webs lying in a common plane. An analysis and a discussion of the results of tests of full-scale specimens are given, as well as descriptions of the specimens and the testing procedures.

The author offers the following conclusions with regard to rigid steel frames: (1) Panel zones can be the weakest element in frames and are especially important for frames subjected to lateral loads. (2) Doubler plates can be used to increase the shear capacity of panel zones. (3) The shear strains (and stresses) in a web doubler plate are generally less than those in the panel zone web of the reinforced member. However, when the shear strains reach values of three to four times yield, the strains in the doubler plate and the web of the reinforced member become equivalent. (4) When the shear stress in the panel zone of a steel rigid frame is known, the panel zone's contribution to the drift of the frame can be determined. (5) The design criteria for the panel zone given in Section 1.5.1.2 of the *Commentary to the AISC Specification* appear to be realistic. However, when drift is critical and/or web doubler plates are used, the allowable shear stress in the panel zone should be reduced in some cases. The amount of reduction should be based on the desired structural performance.

● 6.2-33 Tene, Y., Epstein, M. and Sheinman, I., **Dynamics of curved beams involving shear deformation,** *International Journal of Solids and Structures,* **11,** *7/8,* July-Aug. 1975, 827-840.

A general analytical and numerical procedure, based on the linear theory, is outlined for the elastic stress and deflection analysis of an arbitrary plane curved beam subjected to arbitrary static and dynamic loads. The equations of motion admit shear deformation and rotary inertia. The numerical solution is obtained by Houbolt's method and by finite differences. The paper also presents two numerical examples.

● 6.2-34 Hegarty, R. F. and Ariman, T., **Elasto-dynamic analysis of rectangular plates with circular holes,** *International Journal of Solids and Structures,* **11,** *7/8,* July-Aug. 1975, 895-906.

The problem of the free vibrations of a rectangular elastic plate, either clamped or simply supported with a central circular hole, is investigated by a least-squares point-matching method. The results are given in the form of curves relating the natural frequency of the plate to the hole size for a variety of Poisson's ratios. The curves do not behave monotonically, and the hole size at which the frequency is a minimum is seen to be dependent not only on the boundary conditions but also on Poisson's ratio. A twofold mechanism of strain relief and mass reduction is proposed to explain these results as well as the results of previous studies on the vibrations of plates with discontinuities.

● 6.2-35 Laura, P. A. A., Maurizi, M. J. and Pombo, J. L., **A note on the dynamic analysis of an elastically re-**

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strained-free beam with a mass at the free end, *Journal of Sound and Vibration*, **41**, *4*, Aug. 22, 1975, 397–405.

This study deals with the determination of natural frequencies and modal shapes of an elastically restrained-free beam that carries a finite mass, M, at the free end. Numerical results are presented for different concentrated mass/beam mass ratios, M/M_v, and a wide range of values of the parameter $\beta EI/L$, where β is the coefficient which relates the angle of rotation and the bending moment at the elastically-restrained end. The variation of the maximum dynamic stress as a function of M/M_v and $\beta EI/L$ also is analyzed for the first mode of vibration.

● **6.2-36** Gladwell, G. M. L. and Vijay, D. K., **Natural frequencies of free finite-length circular cylinders,** *Journal of Sound and Vibration*, **42**, *3*, Oct. 8, 1975, 387–397.

Sets of tables are given for the natural frequencies of the first five symmetric and first five antisymmetric modes of a hollow or solid cylinder for circumferential wave numbers $n = 0, 1, 2$. Contour graphs are given for the lowest frequencies as functions of (length)/(mean radius) and (thickness)/(mean radius).

● **6.2-37** Cheung, Y. K. and Kwok, W. L., **Dynamic analysis of circular and sector thick, layered plates,** *Journal of Sound and Vibration*, **42**, *2*, Sept. 22, 1975, 147–158.

The finite element method is extended to the free vibration analysis of laminated thick plates with curved boundaries. Two elements are developed on the basis of Mindlin's thick plate theory in which the effects of thickness-shear deformation and rotary inertia are included. Both elements are derived in polar co-ordinates and can be joined together to handle annular as well as circular laminated anisotropic plate problems. Since axisymmetry has not been assumed, variations in material properties in the tangential direction can be dealt with. Numerical results are presented to demonstrate the influence of geometrical shape as well as that of thickness-shear deformation on the free vibrations of both homogeneous and layered plates. Comparisons between the numerical results obtained and those presented by other investigators confirm the accuracy of the new elements. The elements also can be used in the analysis of rectangular plates by assuming very large radii and very small subtended angle values.

● **6.2-38** Lin, E. I.-H. and Sackman, J. L., **Identification of the dynamic properties of nonlinear viscoelastic materials and the associated wave propagation problem,** *International Journal of Solids and Structures*, **11**, *10*, Oct. 1975, 1145–1159.

A method is developed for the identification of the dynamic properties of nonlinear viscoelastic materials using transient response information arising from impact tests. The solutions of the identification problem and that of the associated nonlinear wave propagation problem are shown to be coupled. They are accomplished via application of the method of lines, the Runge-Kutta-Pouzet integration scheme with automatic step size control and Powell's method of unconstrained optimization. Numerical experiments are performed to demonstrate the feasibility, accuracy and stability of the solution procedure established, and wave propagation experiments are conducted to investigate the applicability of the method to a real physical system. The results are of particular interest in the modeling of nonlinear viscoelastic materials and the identification of systems governed by nonlinear hyperbolic partial-integro-differential equations.

● **6.2-39** Goel, R. P., **Axisymmetrical vibration of a circular plate having an elastic edge beam and a central mass,** *Journal of Sound and Vibration*, **41**, *1*, July 8, 1975, 85–91.

Eigenfrequencies of transverse vibration of a thin circular plate with an elastic edge beam and a concentrated mass at its center are obtained. Only axisymmetric modes of vibration are considered. The effects on eigenfrequencies of the system produced by varying the ratios of the concentrated mass to the mass of the plate and the stiffness of the edge beam to the stiffness of the plate are presented.

● **6.2-40** Rao, S. S. and Prasad, A. S., **Vibrations of annular plates including the effects of rotatory inertia and transverse shear deformation,** *Journal of Sound and Vibration*, **42**, *3*, Oct. 8, 1975, 305–324.

An investigation of the natural vibrations of isotropic annular plates of uniform thickness has been made by considering the effects of rotatory inertia and shear deformation. The frequency determinantal equations are derived in explicit form for nine sets of common boundary conditions. Numerical results for the frequency parameters of annular plates having various thickness ratios and inner to outer radii ratios have been obtained. Wherever possible, the results are compared with those given by the classical plate theory. The effect of shear deformation has been found to be more prominent than the effect of rotatory inertia.

● **6.2-41** Crawford, J. and Atluri, S., **Non-linear vibrations of a flat plate with initial stresses,** *Journal of Sound and Vibration*, **43**, *1*, Nov. 8, 1975, 117–129.

Nonlinear free vibrations of a simply supported rectangular elastic plate are examined by using stress equations of free flexural motions of plates with moderately large amplitudes derived by Herrmann. A modal expansion is used for the normal displacement that satisfies the boundary conditions exactly, but the in-plane displace-

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

ments are satisfied approximately by an averaging technique. The Galerkin technique is used to reduce the problem to a system of coupled nonlinear ordinary differential equations for the modal amplitudes. These nonlinear differential equations are solved for arbitrary initial conditions by using the multiple-time scaling technique. Explicit values of the coefficients that appear in the forementioned Galerkin system of equations are given in terms of nondimensional parameters characterizing the plate geometry and material properties for a four-mode case. Results for specific initial conditions also are presented for the four-mode case. A comparison of the results with those obtained in previous studies of the problem is presented. In addition, effects of prescribed edge loadings are examined for the four-mode case.

● 6.2-42 Kishore, N. N. and Ghosh, A., **Damping characteristics of elastic-viscoelastic composite curved bars and helical springs**, *Journal of Sound and Vibration*, **43**, *4*, Dec. 22, 1975, 621-632.

The paper deals with the analysis of damping characteristics of a curved composite shaft. The composite shaft consists of an outer elastic curved tube with a similarly curved rod placed inside. The annular space between the tube and the rod is filled with viscoelastic material. The composite shaft is clamped at one end and a concentrated load (varying harmonically) acts on a radial arm fixed to the outer shell at the free end. It is shown that optimum design values exist for maximizing the total damping capacity of the system. It also is indicated that direct use of this method for increasing the damping capacity is not effective, as the damping factor reduces sharply after reaching a maximum value. It is shown how this difficulty can be overcome and how helical springs, possessing considerable damping capacity, can be designed. Sometimes this may help in simplifying the design of vibration isolators which will take the shape of a simple spring only.

● 6.2-43 Sundararajan, C. and Reddy, D. V., **Finite strip-difference calculus technique for plate vibration problems**, *International Journal of Solids and Structures*, **11**, *4*, Apr. 1975, 425-435.

The paper presents the application of the calculus of finite differences to obtain an explicit expression for the natural frequencies of the finite strip model of a simply supported orthotropic rectangular plate. This analytical solution not only involves far less computational work than the conventional finite strip method, but also enables parametric studies for accuracy and convergence of the finite strip approximation.

● 6.2-44 Mostaghel, N., **Stability of columns subjected to earthquake support motion**, *International Journal of Earthquake Engineering and Structural Dynamics*, **3**, *4*, Apr.-June 1975, 347-352.

The problem of stability of an initially straight, simple column, subjected to dynamic overload due to the vertical component of ground acceleration during an earthquake, is considered. The time history of this component of an earthquake, its maximum absolute amplitude and Liapunov's function are used to define a sufficient condition under which the column will always be stable. For the case of a simple column it is shown that this condition implies that the column will be stable as long as the maximum load which the column is subjected to is less than the Euler buckling load during an earthquake.

● 6.2-45 Gladwell, G. M. L. and Vijay, D. K., **Errors in shell finite element models for the vibration of circular cylinders**, *Journal of Sound and Vibration*, **43**, *3*, Dec. 8, 1975, 511-528.

Four commonly used shell theories, membrane, thin, thick and proportional, are compared with an accurate triangular torus cubic finite element method in their ability to predict the natural frequencies and mode shapes of infinite and free-free finite length solid and hollow circular cylinders. In the computation, each shell theory is replaced by a finite element approximation which satisfies the same basic assumptions as the shell theory. Error curves are given for the first two axial-shear, torsional-shear and radial-stretch modes of infinite cylinders. Error contours are given for the first symmetric and first antisymmetric mode of cylinders for circumferential wave numbers $n = 0$, 1, 2.

● 6.2-46 West, H. H., Geschwindner, L. F. and Suhoski, J. E., **Natural vibrations of suspension cables**, *Journal of the Structural Division, ASCE*, **101**, *ST11*, Proc. Paper 11712, Nov. 1975, 2277-2291.

Natural frequencies and modes of vibration for suspension cables are determined using a discretized system composed of a linkage of straight bars connected by frictionless pins with concentrated masses at the connection points. The governing equations are linearized, which limits the applicability to small oscillations. The frequencies are determined by a generalized Holzer method coupled with the solution of the associated boundary value problem as a set of initial-value problems. The method is applied to sample numerical problems, and the results are compared with the results obtained by alternate approaches. The sensitivity of the results to the nature of the discretization is studied. Also, several parameter studies are conducted to determine how the natural vibrations are altered in response to dimensional variations in the suspension cable. The results of the parameter studies are summarized in a nondimensional form.

● 6.2-47 Desayi, P., Iyengar, K. T. S. R. and Reddy, K. N., **Ductility of reinforced concrete sections with confined compression zones**, *International Journal of Earthquake*

Engineering and Structural Dynamics, **4**, *2*, Oct.–Dec. 1975, 111–118.

Confinement of concrete in circular spiral steel binders imparts to it considerable ductility and also some increase in strength. This property can be utilized in designing concrete structures to withstand seismic forces where the members are required to possess not only strength but also energy-absorbing capacity. Assuming the stress-strain behavior of confined concrete as elastic-plastic, the ductility factor for strain and the strength factor (denoting increase in strength) have been determined for concrete confined to different degrees. Similarly, assuming the moment-curvature behavior of reinforced concrete sections with confined compression concrete to be elastic-plastic, the ductility factor for curvature has been determined for such beams. The computed moment-curvature plots have been found to compare satisfactorily with tests on 18 beams. Ductility factors for curvature of singly and doubly reinforced concrete sections with compression concrete confined to different degrees have been determined and presented for certain typical cases. Such plots would be of use in designing reinforced concrete beam sections for required ductility.

● **6.2-48** Rutenberg, A., **Approximate natural frequencies for coupled shear walls**, *International Journal of Earthquake Engineering and Structural Dynamics*, **4**, *1*, July–Sept. 1975, 95–100.

An approximate yet accurate formula is proposed for the natural frequencies of coupled shear walls under continuous medium assumptions. First, the deflected shape of the structure is represented as the sum of two components: one due to flexural cantilever action and one due to shear-flexure cantilever action. The natural frequencies of the latter two systems are then combined in Dunkerley's formula to yield the approximate frequency of the structure.

● **6.2-49** Rosman, R., **Dynamic properties of some modern building systems**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 67, 12. (For a full bibliographic citation see Abstract No. 1.2-8.)

Simple formulas and tables of corresponding coefficients are given for the fundamental periods of shear-wall systems, coupled shear-wall systems, shear-wall-frame systems, frame systems and stacked frame systems. These formulas and tables enable rapid, simple analyses to be made of the response of the structures when subjected to earthquakes.

● **6.2-50** Kisliakov, S., **On the mean-square dynamic stability of some elastic systems**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 81, 4. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper the dynamic stabilities of a rod, a rectangular plate, and a cylindrical panel, all considered as elastic systems, are investigated. The loading is a wide-band random process, which is approximately described by a white noise signal. After use of Bubnov-Galerkin's method, all of the above-mentioned problems can be reduced to ordinary differential equations with random parametric excitation. For the single-degree-of-freedom first approximation, the mean-square stability is investigated. A "critical power spectral density" is introduced and studied.

● **6.2-51** Negoita, A. and Dumitraş, M., **On the ductility of prestressed normal and lightweight concrete bent members**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 66, 11. (For a full bibliographic citation see Abstract No. 1.2-8.)

The paper contains a discussion of the definition of the ductility factor and the parameters of ductility. Experimental tests of prestressed heavy and lightweight concrete beams are described. It is concluded that these beams have sufficient ductility to be used in earthquake-resistant structures.

● **6.2-52** Gawronski, W., **The effect of system parameter variations on natural frequencies**, *Computers and Structures*, **5**, *1*, Apr. 1975, 31–43.

In this paper the relationships between variations of mass and stiffness matrices of a system and the variation of natural frequency vectors are analyzed. Results are applied to the finite element method and to the stiff finite element method. The example of influence of masses and mass inertia moment variations of a support beam on its natural frequencies illustrates the analysis.

6.2-53 Nemchinov, Yu. I. and Tolbatov, Yu. A., **Free vibrations of shallow cylindrical shells with stiffening ribs** (Svobodnye kolebaniya pologikh tsilindricheskikh obolochek podkreplennykh rebrami zhestkosti, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii*, *3*, 1975, 55–57.

Free vibrations of shallow cylindrical shells with stiffening ribs along generators and parallels are investigated. The eccentricity of the stiffening ribs relative to the median surface of the shell is taken into account. The results obtained in the paper may be used to calculate natural frequencies, mode shapes and seismic loads on roofs of industrial buildings of a type widely used in construction practice.

6.2-54 Zorii, L. M. and Tatsii, R. M., **Investigations of vibrations and stability of elastic plates of arbitrary shape** (K issledovaniyu kolebanii i ustoichivosti uprugikh plastinok proizvolnoi formy, in Russian), *Doklady Akademii Nauk Ukrainskoi SSR, Seriya A,* 2, 1974, 154-157.

An effective method for finding critical loads and fundamental vibration frequencies of uniformly loaded elastic plates of arbitrary shapes clamped around their contour is presented. The method is based on conformal mapping techniques, use of eigenvalues of "characteristic series" and applications of upper and lower estimates.

6.2-55 Ambriashvili, Yu. K. *et al.*, **Strength and deformability of concrete and reinforced concrete structures under seismic loads** (Prochnost i deformativnost betonnykh i zhelezobetonnykh konstruktsii pri seismicheskikh vozdeistviyakh, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki, 87,* 1973, 15-22.

Dynamic properties of concrete and reinforced concrete structural elements are studied. Future research problems are formulated.

6.2-56 Dzhavakhishvili, V. Sh., **On the problem of calculating natural frequencies of beamless floor slabs** (K voprosu opredeleniya chastot sobstvennykh kolebanii bezbalnochnykh perekritii, in Russian), *Trudy Gruzinskogo Politekhnicheskogo Instituta, 5,* 1974, 22-26.

The problem of free vibrations of a rectangular plate supported along its contour and by columns arranged in a quadratic pattern is considered. The column heads are assumed elastic. The problem of vibrations in a plate with varying stiffness on an elastic base is studied and natural frequencies are calculated using a double trigonometric series. The natural frequencies of beamless floor slabs are derived by incorporating the effects of columns with variously shaped column heads. Numerical examples of natural frequency calculations are given.

6.2-57 Yamaguchi, I. and Araki, T., **Study on deformable shear walls** (in Japanese), *Transactions of the Architectural Institute of Japan, 227,* Jan. 1975, 13-23.

Reinforced concrete shear walls are not always the most advantageous to use in the design of structures. This is due to the fact that, despite their high degree of strength, they have a high degree of stiffness and a small degree of ductility. Thus deformable shear walls, i.e. walls with a high degree of strength, a low degree of stiffness and a large degree of ductility, have been required.

Deformable shear walls using flexible connectors between steel frames and reinforced concrete walls are studied. To examine the general behavior of such walls, static tests up to failure were carried out on six specimens.

In addition, based on the test results, the authors established a system of elastic analysis of tall buildings with deformable shear walls. Frames are analyzed by the slope-deflection method in the analysis. Deformable connectors are assumed to be the springs, and the finite element method is applied to the analysis of the reinforced concrete walls. Comparison between results obtained by the analysis and the experiments proved that this method of analysis is reasonable.

Using this method of analysis, the authors examined the relation among the frames, the deformable connectors and the walls for tall buildings of N stories with one bay.

6.2-58 Noguchi, H., **Study on mechanical behavior of reinforced concrete columns–Part 1: On the outline of experiments, flexural deflections, strain of reinforcing bars and concrete** (in Japanese), *Transactions of the Architectural Institute of Japan, 233,* July 1975, 83-93.

The purpose of this study is to determine the influence of various factors on the strength and ductility of reinforced concrete columns. Columns subjected to bending moment, shearing force and axial force were tested with emphasis on deflection, strain and bond-slip measurements. The effect of material behavior on a column member was studied. Further investigation was made by comparing the test results with the results of an analysis using some of the test results. Two identical specimens were tested. One specimen was subjected to monotonic loads and the other was subjected to cyclic loads.

A number of measurements were taken. Deflections were measured using displacement meters and dial gauges; strain of reinforcing bars and concrete was measured using wire strain gauges; average strain of concrete was measured using a contact gauge; bond slip was measured directly using a contact gauge and was calculated from strain; cracks were observed. Load-deflection relationships, curvature-distribution diagrams, flexural deflections and load-strain relationships are shown and discussed in comparison with the results of the analysis.

6.2-59 Hayashi, K., **Studies on the shear strength of wooden wall panels with opening–Part 1: The proposal formulae to estimate shear stiffness of wooden wall panels with plywood sheathing** (in Japanese), *Transactions of the Architectural Institute of Japan, 233,* July 1975, 33-38.

In order to estimate the real shear strength of prefabricated wooden structures from results of unit-panel racking tests, it is necessary to know how wooden wall panels with openings perform. For this purpose, the author proposes three theoretical formulas for estimating the shear strength of the following types of panels: (a) window-type and horizontal slit-type opening panels, (b) door-type and vertical slit-type opening panels with spandrel wall, (c) vertical slit-type opening panels without spandrel wall. The formulas are proposed based on the assumption that the entire panel undergoes a pure shear deformation in cases (a) and (b) and that the wing walls undergo a rotatory deformation in the case of (c).

6.2-60 Kato, S., Murata, M. and Matsuoka, O., **Dynamic buckling analyses of rotational shells by combined finite element and mode superposition method—Part 4: Asymmetric dynamic buckling analyses of shallow clamped shells subjected to the simultaneous action of uniform lateral pressure and concentrated force on the apex** (in Japanese), *Transactions of the Architectural Institute of Japan, 236*, Oct. 1975, 27–33.

Asymmetric dynamic buckling loads of shallow caps with parameter λ = 5, 6, 7 and 7.5 are obtained numerically. The asymmetric buckling is found to begin with the Mathieu-type oscillation between the symmetric and asymmetric deformations; however, the magnitude of the asymmetric displacements is too small to compare with the symmetric ones. The critical uniform step load of 0.40 for λ = 7.5 gives good agreement with the experimental results investigated by M. H. Lock *et al.*, for which the step load ranges from 0.364 to 0.438.

6.2-61 Tsuboi, Y., **Parametric study of elastic buckling of shells with reference to Gaussian curvature—Part IV: Buckling of shells in bending state—Nonlinear problem (2)** (in Japanese), *Transactions of the Architectural Institute of Japan,* 233, July 1975, 71–81.

This paper discusses the critical load and the deformation for bifurcation buckling of flat shells under uniform external pressure. The theory is presented in terms of a stress function for membrane stress and normal displacement. Bifurcations in symmetric and antisymmetric modes are considered.

6.2-62 Kato, B. and Akiyama, H., **Lateral buckling of elastic H-section beams with continuous restraints on upper flange** (in Japanese), *Transactions of the Architectural Institute of Japan*, 232, June 1975, 41–50.

Basic equilibrium equations were derived for calculating the buckling strength of H-section beams under various kinds of restraints. These equations, which are equivalent to the classical differential equations for the problem, are easily applied to the complicated problem of buckling.

The buckling strength of beams under restraints exerted by slabs resting on the beams was analyzed using the derived equations. The beams were subjected to bending moment about the strong axis at both ends of the beams. It was found that the torsional restraint due to the flexural rigidity of the slabs could enhance considerably the buckling strength. Numerical results are summarized with simple formulas. With these formulas, the influence of the flexural rigidity of a slab on beam buckling strength can be estimated readily.

6.2-63 Yamada, M. and Kawamura, H., **Aseismic capacity of steel structures—II Applications: Rigid frames without braces composed of H-columns** (in Japanese), *Transactions of the Architectural Institute of Japan, 230*, Apr. 1975, 29–35.

Analytical equations and methods for determining the flexural deformation and fatigue characteristics of structural members and sections composed of plate elements were presented in Part I.

To check on the reasonableness of the equations and methods, calculations are carried out on H-columns, and the results are compared with test results. The equations were used to estimate the seismic-resistant capacity of column-yielding type rigid frames without braces, composed of 300 mm series H-columns. It is shown that cross-sectional area ratios between the flange and web elements of H-sections and axial load level ratios are the main factors for the seismic-resistant safety of such frames and that the critical load level ratio is found to be about 1/6.

● 6.2-64 Radhakrishnan, V. M., **Strain intensity factor and low cycle fatigue**, *Iranian Journal of Science and Technology*, 4, *1*, 1975, 9–16.

Investigations have been carried out to find the effect of notch depth on the fracture strain of different materials. Low-cycle fatigue tests are also carried out to analyze the crack propagation and the effect of fatigue crack on the remaining ductility of the material. It has been found that the fracture strain of the material is reduced in the presence of a crack or a notch. The concept "strain intensity factor" has been developed in terms of the applied strain and the crack length, which appears to give a reasonable basis for the analysis of fracture under general yielding condition. The crack propagation rate in low-cycle fatigue has been found to be a function of the strain intensity factor. The ductility of the material reduces with increasing number of fatigue cycles.

6.2-65 Suzuki, T., **Lateral buckling stress of H-shaped steel beams (Study on the lateral buckling of steel beams)** (in Japanese), *Transactions of the Architectural Institute of Japan, 229*, Mar. 1975, 43–51.

The lateral buckling of I-shaped beams under axial force and the end couples in plan of the web are examined. The problem of buckling behavior can be looked at as column buckling of a compression flange in the weak direction. The equilibrium equations of lateral buckling are derived in terms of the lateral deformation of each flange of I-shaped beams. The approximate buckling stress for

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

doubly symmetric I-shaped beams is obtained by measuring the adequate slenderness ratio of the compression flange of the beams. As a result of substituting the actual value of I-shaped beams including wide flange sections and plate girders, it is made clear that the resulting equation closely approximates the exact solution. The lateral buckling problems of I-shaped beams with unequal flanges also are analyzed, and similar results are obtained.

Finally, on the basis of these results, design formulas for bending I-shaped beams and plate girders are presented. These results are compared with AIJ design formulas.

● 6.2-66 Mayes, R. L. and Clough, R. W., **A literature survey - Compressive, tensile, bond and shear strength of masonry**, *EERC 75-15*, Earthquake Engineering Research Center, Univ. of California, Berkeley, June 1975, 211. (NTIS Accession No. PB 246 292)

The literature survey presented collates most of the available relevant information on the compressive, tensile, bond and shear strength of masonry. The report is divided into two chapters. The first, on the compressive, tensile and bond tests of small test specimens, summarizes information on the basic tests that determine different properties of nonhomogeneous, masonry assemblages. These basic tests are important in that they provide practical methods for the site control of masonry quality by measuring the integrated effect of any variations in component materials and workmanship.

The second chapter summarizes most investigations performed on the shear strength of different assemblages and includes sections on test techniques, monotonic tests, model tests and cyclic tests.

Further discussion and analysis of the results from the experiments described here are presented in the following Earthquake Engineering Research Center report EERC 75-21.

● 6.2-67 Mayes, R. L. and Clough, R. W., **State of the art in seismic shear strength of masonry - An evaluation and review**, *EERC 75-21*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1975, 147. (NTIS Accession No. PB 249 040/AS)

The state-of-the-art report presented attempts to review and evaluate all the relevant research performed on the shear strength of masonry subassemblages. The report is divided into thirteen sections. Seven sections examine the effects of parameters such as grout, mortar, type of bond, reinforcement, bearing load and rate of loading on the shear strength of subassemblages while the other six evaluate the characteristics of the modes of failure and inelastic behavior of the subassemblages.

6.3 Dynamic Properties of Linear Structures

6.3-1 Coull, A., **Free vibrations of regular symmetrical shear wall buildings**, *Building Science*, **10**, 2, July 1975, 127-133.

The continuous connection method is employed to analyze the free bending and torsional vibrations of regular symmetric cross-wall structures. The natural modes and frequencies of vibration are determined from the Galerkin technique. The theoretical analysis is illustrated by a numerical example of a typical representative structure.

6.3-2 Yakubov, Sh. M., **Dynamic testing of minarets** (Dinamicheskie ispytaniya minaretov, in Russian), *Stroitelstvo i arkhitektura Uzbekistana, 6*, 1975, 48-50.

Results of investigations of the dynamic properties of four minarets in Samarkand, Bukhara and Khiva are presented. Amplitudes, natural frequencies and logarithmic damping decrements were measured. The dynamic response characteristics of the minarets were found to meet current standards.

6.3-3 Losaberidze, A. A. *et al.*, **The worst direction of seismic waves in evaluating earthquake response of arch dams** (Opredelenie naikhudshego napravleniya voln zemletryasenii pri otsenke seismostoikosti arochnykh plotin, in Russian), *Stroitelnaya mekhanika prostranstvennykh konstruktsii*, 1974, 102-106.

Within the framework of the spectral method used in calculating seismic forces in arch dams, a technique for finding extremal values of the vibration parameters of a dam is presented. In the case of horizontal seismic excitation, the skew-symmetric vibration modes corresponding to lateral direction of arriving seismic waves are found to be the most critical.

● 6.3-4 Wang, T. M., Kieronski, J. F. and Marquis, J. P., **Effect of rotary inertia and shear on natural frequencies of cantilever bridges**, *Journal of Sound and Vibration*, **40**, *4*, June 22, 1975, 513-520.

A study of the natural frequencies of cantilever bridges, including the effects of rotary inertia and shear deformation, is presented. The bridge is assumed to act as a series of elastic beams with distributed mass. Frequency equations are derived for the symmetric and the antisymmetric vibrations. Values of the frequency parameter owing to the rotary inertia and shear effects are presented and compared with those obtained by classical analysis.

● 6.3-5 Mead, D. J., **Wave propagation and natural modes in periodic systems: II. Multi-coupled systems, with**

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

and without damping, *Journal of Sound and Vibration,* **40,** *1,* May 8, 1975, 19–39.

Free waves can propagate through periodic systems only in particular frequency zones. Equations for the bounding frequencies of these zones are obtained in terms of the receptance matrices of the elements of multicoupled systems. The relationship between these frequencies and the natural frequencies of a single element of the system is considered, particular attention being given to elements which are symmetrical. The nature of the characteristic wave motions is studied, and a characteristic receptance matrix for a characteristic wave is defined. This is used to introduce the study of reflection of a characteristic wave from a boundary. The equations governing the reflection process are set up and used to formulate the equations for the natural frequencies and modes of a finite periodic system with arbitrary boundaries. The modes are represented by superpositions of opposite-going pairs of characteristic waves, in terms of which a simple physical description of the natural wave motion is presented.

Undamped systems are considered initially, but it is then shown that all the equations so derived for free wave motion are applicable to the damped forced motion of hysteretically damped multicoupled systems. The bounding frequencies and loss factors of purely propagating damped forced wave motion are considered in relation to the resonant frequencies and loss factors of the damped forced normal modes of a single element. Finite periodic systems of damped multicoupled elements are finally studied.

● 6.3-6 Sinitsyn, A. P., **Overall stability of tall buildings in strong earthquakes** (Obshchaya ustoichivost mnogoetazhnykh zdanii pri silnykh zemletryaseniyakh, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 3–7.

Conditions leading to buckling of tall buildings in strong earthquakes are investigated. The analysis is based on the effects of plastic and elastic waves traveling in the sedimentary layer forming the base of the structure.

● 6.3-7 Croll, J. G. A., **Coupled vibration modes,** *Journal of Sound and Vibration,* 38, *1,* Jan. 8, 1975, 27–37.

The dynamic response of a simple two degree-of-freedom mechanical analog is investigated to illustrate the nature of mode interaction that exists for systems in which the stiffness against vibration in one mode is sensitive to the amplitude of the vibration response in the second possible mode. This model shows that over a range of excitation energy input, dependent upon the damping characteristics and the separation between the two uncoupled natural frequencies of small vibration, a multiplicity of resonant frequencies will be observed to occur in the first mode. In some situations, and above a certain supercritical energy input level, it becomes impossible to observe the resonance that would be predicted from an uncoupled small vibration analysis of this first mode. It is suggested that this phenomenon could be displayed in a more complex manner in the dynamic response of a wide range of shell and shell-like structures.

● 6.3-8 Done, G. T. S. and Hughes, A. D., **The response of a vibrating structure as a function of structural parameters,** *Journal of Sound and Vibration,* 38, *2,* Jan. 22, 1975, 255–266.

The response of a structure excited by an external oscillatory force is examined for variations in certain structural parameters of the system. This is done with a view to manipulating the structure in order to achieve a desired response. The variation of the response with one structural parameter is seen to be simple, and the effect of changing the forcing frequency in addition is illustrated. When two structural parameters are considered, it is seen that a desired response may or may not be attainable, as defined by a "feasible response region." The application to practical cases is discussed briefly.

● 6.3-9 Zaurov, D. B., **Parametric method of analysis of vibration records of structures** (Parametricheskii metod analiza vibrogram kolebanii sooruzheniya, in Russian), *Seismostoikost plotin, 3,* 1975, 134–143.

The fundamental dynamic properties of a structure (natural frequencies, mode shapes and damping coefficients) are calculated using the spectral method, involving analysis of the entire vibration process on computers with a great volume of memory. The analysis is substantially simplified by the use of the parametric method discussed in the paper.

● 6.3-10 Radhakrishnan, R., **Frequency response of tower-shaped structures,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 35–38.

This paper describes an investigation into the modal characteristics and damping in a tower-like structure subjected to transient and steady-state forced vibrations. The two models, constructed of mild steel bars and angles, were tested and the results are compared with theoretical values.

● 6.3-11 Ewins, D. J., **Estimation of resonant peak amplitudes,** *Journal of Sound and Vibration,* 43, *4,* Dec. 22, 1975, 595–605.

A simple method is proposed for estimating the resonant peak response levels of damped structures by using an analysis of undamped vibration. The method is based on a simple identity which is exact for a single-degree-of-freedom system and approximate for more general systems.

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However, since the level of damping in practical structures can seldom be described with any precision, it is argued that a simple approximate method for predicting resonant vibration levels is the most appropriate. A number of examples and applications are described.

● 6.3-12 Mee, A. L., Jordaan, I. J. and Ward, M. A., **Dynamic response of a staggered wall-beam structure,** *International Journal of Earthquake Engineering and Structural Dynamics,* 3, *4,* Apr.-June 1975, 353-364.

A method for the dynamic analysis of staggered wall-beam frames is developed using consistent mass terms, which are derived and given in simple terms. The method uses effective stiffnesses for wall-beam elements, developed in an earlier paper. Experiments using a nine-story 1:15 scale perspex model are described. The first three natural frequencies of the model were obtained using two methods: sinusoidal external excitation of the structure with the base fixed and white noise excitation employing a single-degree-of-freedom shaking table, in the latter method with and without the addition of mass throughout the model. Agreement between analytical predictions of the first three natural frequencies and mode shapes and experimentally determined values is considered satisfactory, particularly for the first two modes. The lumped mass assumption gave reasonable results for these two cases, whereas the consistent mass theory gave reasonable results for the first three natural frequencies.

● 6.3-13 Nair, R. S., **Overall elastic stability of multistory buildings,** *Journal of the Structural Division, ASCE,* **101,** *ST12,* Proc. Paper 11762, Dec. 1975, 2487-2503.

Procedures are presented for the three-dimensional analysis of the overall elastic stability of multistory buildings and for the inclusion of stability effects in lateral-load analysis. The effect of axial force on the flexural stiffness of individual members is neglected. Floors are treated as diaphragms that are rigid in the horizontal plane. The suggested procedures do not require the solution of nonlinear systems of equations or nonlinear eigenvalue problems. The proposed techniques were used to study several 20-story buildings whose structural framing systems were designed in accordance with current engineering practice. The results of these analyses indicate that buildings designed without regard to overall elastic stability can have very low factors of safety against elastic buckling, especially in a torsional mode; second-order effects can cause substantial increases in the displacements and stresses due to wind and other horizontal loads.

● 6.3-14 Pekau, O. A., **Seismic energy dissipation in frame structures,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 259-266.

Results of a study of the seismic energy response of a series of elastic-plastic multistory framed structures are presented. Parameters investigated include, among others, degree and type of viscous damping, seismic intensity, and frequency dependence. Emphasis is on the significance to seismic energy response of the parameters related to the physical distribution of member stiffness and strength over the height of the structure. To relate peak seismic energy demand with the structural energy capacity under static loading, ratios of dynamic-to-static energies are studied. The data show that static capacity can be employed profitably in evaluating the expected potential for earthquake energy dissipation. In particular, it is found that weak-column structures are characterized by high ratios of seismic demand to static capacity, while strong-column structures lead to correspondingly low ratios. These low energy ratios are shown to be accompanied by effective dissipation of the seismic energy input at acceptable levels of member ductility response.

● 6.3-15 Mayes, R. L. and Mowbray, N. A., **The effect of Coulomb damping on multidegree of freedom elastic structures,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3,** *3,* Jan.-Mar. 1975, 275-286.

This paper is based on the premise that the damping mechanism of a multidegree-of-freedom structure can be represented by viscous and Coulomb dampers. A closed-form solution is presented for the structure subjected to a sinusoidal forcing function. The solution is used as the basis of a method for determining relative amounts of viscous and Coulomb damping from vibration tests. The method was applied to the results of a series of vibration tests on a five-story reinforced concrete structure and approximate values of viscous and Coulomb damping obtained. A comparison of the effect of various combined damping values on the earthquake response of the structure was made. It was concluded that the use of the equivalent viscous damping concept to approximate the combined effect of viscous and Coulomb damping results in a low estimate of the elastic response of the structure.

● 6.3-16 Balsara, J. P. and Norman, C. D., **Vibration tests and analysis of a model arch dam,** *International Journal of Earthquake Engineering and Structural Dynamics,* **4,** 2, Oct.-Dec. 1975, 163-177.

Vibration tests were conducted on a 1/24-scale model of the North Fork Dam, a double-curvature arch dam, to determine natural frequencies, mode shapes and hydrodynamic pressures. The mode shapes and natural frequencies were determined from tests using two vibrators mounted on the crest of the dam. Hydrodynamic pressures at the dam-reservoir interface were determined from tests in which the vibrator was attached to the downstream foundation of the dam. The hydrodynamic pressures, calculated

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using Westergaard's theory, and a theory for arch dams, developed by Perumalswami and Kar, accurately predicted the measured pressure at frequencies below the first mode frequency of the dam. The differences in the two theories were insignificant.

The Structural Analysis Program (SAP), a linear three-dimensional (3-D) finite element code, was used to compute mode shapes and frequencies for the dam with its base fixed and with a foundation. Numerical solution schemes used in the finite element analysis consisted of a Ritz analysis and a subspace iteration method. Calculations were conducted for both full and empty reservoir conditions.

The accuracy of the Ritz analysis improved considerably as more nodes in flexible regions of the dam were loaded. However, the lowest eigenvalues were computed using the subspace iteration method. For the full reservoir, the natural frequencies decreased by 20–30 per cent when the foundation was included in the finite element model. The difference was less when the reservoir was empty. The calculations using the subspace iteration scheme and including the foundation agreed closely with experimental mode shapes and corresponding natural frequencies.

● **6.3-17** Udwadia, F. E., **On some uniqueness problems in building systems identification from strong motion records**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 70, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper investigates problems in the determination of the structural parameters of a building system from records obtained during strong ground shaking. Through an analysis of a linear two-degree-of-freedom system, conditions under which uniqueness follows have been investigated. The studies indicate that uniqueness may be obtained by proper instrumental locations but that roof and basement records, which are often used in studies of building identification, do not have sufficient information in them to uniquely determine the estimates of structural stiffness and damping.

● **6.3-18** Pollner, E. and Groper, M., **Damping of large-panel buildings**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 102, 9. (For a full bibliographic citation see Abstract No. 1.2-8.)

The connections in large-panel buildings are usually the weak link in the structural system called upon to resist seismic forces. The connections will, therefore, sustain plastic deformations, cracking, and other local damage, while the other parts of the structure remain elastic. Accordingly, the energy absorption capacity and the strength of the connections will decisively influence the damping and earthquake response of such buildings.

6.3-19 Tseitlin, A. I., **On the theory of internal friction in vibrating elastic systems** (K teorii vnutrennego treniya pri kolebaniyakh uprugikh sistem, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2*, 1975, 51–56.

The suitability for nonstationary vibrations of the hypothesis of frequency-independent internal resistance in complex form (called Sorokin's hypothesis in Soviet literature) is investigated. A model of frequency-independent resistance is constructed in the form of a regularized integral operator with a Boltzmann kernel and a more precise formulation of the hypothesis is given. In the case of nonstationary vibrations, the use of the hypothesis is equivalent, after separation of the stable part of the solution, to the frequency-independent model of viscoelastic resistance. The kinetic equations for the latter model are constructed.

6.3-20 Vakhromeev, Yu. M., **On asymptotic integration of vibration equations of a bar** (Ob asimptoticheskom integrirovanii uravnenii kolebaniya sterzhnya, in Russian), *Dinamika sploshnoi sredy, 14*, 1973, 30–36.

Higher free vibration frequencies of an inhomogeneous bar are calculated under various types of boundary conditions. A reduced problem is formulated. The eigenvalues of the reduced problem are close to those of the original problem provided the latter are sufficiently large. In contrast to the case of a homogeneous bar, the fundamental functions of the reduced problem will be asymptotically close to those of the initial problem only after multiplication by a weight function. The problem of vibrations in a three-layered bar is considered.

6.3-21 Kobidze, G. N. *et al.*, **The problem of calculating maximal seismic stresses in cross sections of tower structures using accelerograms of strong earthquakes** (Vopros opredeleniya maksimalnykh seismicheskikh napryazhenii v secheniyakh sooruzhenii bashennogo tipa pri ispolsovanii akselerogramm razrushitelnykh zemletryasenii, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 89–97.

The example of the absorption tower of the Nakhichevani soda factory is employed to illustrate the techniques used in calculating maximum seismic stresses in cross sections of tower structures with the aid of an M-220 computer. The structure is approximated by a cantilever with 15 concentrated masses. Using the spectral method, the authors calculate the first four natural frequencies and bending moments in each of the cross sections for peak accelerations of 0.15 g.

6.3-22 Tomii, M. and Yamakawa, T., **Relations between the nodal external forces and the nodal displacements on the boundary frames of rectangular elastic framed shear walls—Part I: Relations between the nodal external forces and the representative components of their fundamental**

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components, *Transactions of the Architectural Institute of Japan*, 237, Nov. 1975, 45-53.

The relations between the nodal external forces and the nodal displacements on boundary frames of rectangular elastic framed shear walls are shown in matrix form. The general stiffness matrix and general flexibility matrix are expressed in terms of the fundamental flexibility matrix given analytically or experimentally. The fundamental flexibility matrix for symmetric rectangular framed shear walls assumed to be isotropic elastic bodies can be given by using the strict elastic analyses reported by M. Tomii and others, and the elements of the general stiffness matrix and general flexibility matrix for the framed shear walls are expressed in terms of the elements of the fundamental flexibility matrix. The load terms and rigid-body motion terms in the relations also are mentioned.

The relations revealed in this paper can contribute to matrix structural analyses for earthquake-resisting framed structures in which the framed shear walls are arranged apart.

6.3-23 Sumchenko, E. I., **On the effects of tangential displacements and resulting inertial forces on natural frequencies and mode shapes of arch dams** (Ob uchete kasatelnykh peremeshenii i sil inertsii ot nikh pri opredelenii chastot i form sobstvennykh kolebanii arochnykh plotin, in Russian), *Seismostoikost bolshikh plotin*, 1973, 74-77.

The method for calculating natural frequencies and mode shapes of arch dams developed by I. A. Konstantinov and A. A. Stotsenko is presented in detail. Following an outline of the theory, the natural frequencies and mode shapes are calculated taking into account both radial and tangential displacements and the resulting inertial forces for those types of arch dams for which earlier calculations took into account only the radial displacements. The effects of tangential displacements and the resulting inertial forces are clearly shown in the frequency increase found in the skew-symmetric vibration modes.

6.3-24 Yamada, M. and Kawamura, H., **Aseismic capacity of steel structures—I. Fundamental: Rigid frames with and without braces** (in Japanese), *Transactions of the Architectural Institute of Japan*, 227, Jan. 1975, 67-74.

The seismic-resistant capacity of steel structures composed of rigid frames with and without braces is presented as a figure illustrated in the space whose coordinates are acceleration response factor, natural period and damping coefficient. This figure shows that it is reasonable for strength to be taken as the earthquake-resisting factor for frames with braces and for hysteretic damping capacity to be taken as the earthquake-resisting factor for frames without braces.

For frames without braces, the hysteretic damping capacity is estimated analytically, based upon the flexural deformation mechanisms and fatigue characteristics of the structural members and sections composed of plate elements. By applying the hysteretic damping capacity to the steady-state resonance of structures subjected to forced sinusoidal ground vibrations, a firm estimation procedure of the seismic-resistant capacity of rigid steel frames without braces is proposed.

● 6.3-25 Torkamani, M. A. M. and Hart, G. C., **Building system identification using earthquake data**, *EWE 75-01, UCLA-ENG-7507*, Earthquake and Wind Engineering Lab., Univ. of California, Los Angeles, Jan. 1975, 440.

A new procedure is presented for estimating structural parameters in structural dynamics and particularly in earthquake engineering inverse problems.

Two methods were applied to hypothetical one- and two-story frame buildings excited by harmonic input motion and the Golden Gate Park S80E earthquake, and to a real building (the Holiday Inn located on Orion Avenue in Los Angeles), which was involved in the San Fernando earthquake.

The first method provided less accurate estimates in the earthquake cases than in the harmonic cases, probably because of the random, irregular variation of the input data. The second method involved the use of a smoothed estimate of the unit impulse response function.

On the basis of the theory presented, the method of system identification is capable of identifying all structural parameters, e.g. element stiffness and element viscous damping factors.

● 6.3-26 Kircher, C. A., **Determination of the dynamic characteristics of full scale structures by the application of Fourier analysis**, *20*, The John A. Blume Earthquake Engineering Center, Stanford Univ., Nov. 1975, 213.

The methodology and analytical tools needed for the determination of the dynamic characteristics of full-scale structures are presented. The results of investigations of the following structures are presented: (1) 8 story, reinforced concrete building, 533 S. Fremont St., Los Angeles; (2) 32 story, steel frame building, 5900 Wilshire Blvd., Los Angeles; (3) 13 story, reinforced concrete building, 15250 Ventura Blvd., Sherman Oaks; (4) Guy West Suspension Bridge, Sacramento; (5) Hoover Tower, Stanford; (6) support structure, Devil's Canyon P.P.; (7) air blast circuit breakers, Pearblossom P.P.; (8) tower (T-5E), Oso P.P.; (9) disconnect switch, A. D. Edmonston P.P.; (10) bus support, Windgap P.P.; (11) superstructure, Wheeler Ridge P.P.; (12) two-story, industrial building, California Ave.; (13) industrial storage racks, San Francisco Bay Area.

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Each investigation presented the Fourier spectra of the acceleration or displacement vibration records. From the spectra, the natural frequencies were determined. The RMS value of acceleration or displacement was also calculated for most measurements. The damping, measured by the 3 dB level of the log magnitude representation of the power spectrum, was calculated whenever possible.

● 6.3-27 Stephen, R. M. *et al.*, **Dynamic properties of an eleven story masonry building,** *EERC 75-20,* Earthquake Engineering Research Center, Univ. of California, Berkeley, July 1975, 57. (NTIS Accession No. PB 246 945/AS)

This report describes the experimental and analytical studies of the dynamic behavior of the Oak Center Towers Building, a reinforced masonry structure, eleven stories in height, located in Oakland, California. The 100 ft high building has a overall plan of 85 ft by 200 ft. The building is offset in the middle by approximately 16 ft so that it does not have a pure rectangular plan. The major part of the building is made up of studio apartments which are basically 16 ft by 27 ft in plan.

The experimental work consisted of forced vibration studies in which the natural frequencies, mode shapes and damping values are determined. The experimental values are compared to the analytical model results. The fundamental frequencies determined agreed fairly well; however, the higher mode frequencies did not agree as well. Considerable flexibility of the foundation was noted in the experimental studies and by using these displacements in developing the analytical model the agreement in the fundamental modes was achieved.

6.4 Deterministic Dynamic Behavior of Linear Structures

● 6.4-1 Iwasaki, T., **Response analyses of civil engineering structures subjected to earthquake motions,** *Technocrat,* 7, *6,* June 1974, 64-86.

Dynamic response analyses of highway bridges, earth and rockfill dams and submerged tunnels located in Japan are described. A summary of the seismic record and the response spectrum methods used to study ten highway bridges is presented; response analyses of four of these bridges are described in detail. A method proposed by Clough and Chopra is used to study a 300-ft high triangular earth dam section while a method proposed by Watanabe is used to study a cross section of a rockfill dam. The studies of the submerged tunnels were performed on a cross section of the proposed Yokohama Bay Undercrossing Tunnel, a cross section of the proposed Tokyo Bay submerged tunnel and a longitudinal section of a submerged tunnel consisting of nine reinforced concrete elements.

6.4-2 Nemchinov, Yu. M. and Tolbatov, Yu. A., **Seismic loads on stiffened cylindrical shells** (Seismicheskie nagruzki na tsilindricheskie obolochki podkreplennye rebrami zhestkosti, in Russian), *Seismostoikoe stroitelstvo v UzSSR,* Fan, Tashkent, 1974, 104-107.

Seismic loads on a cylindrical shell stiffened by stringers which are positioned eccentric to the shell surface are calculated. Vertical and horizontal vibrations of the shell are considered. Numerical results of seismic forces for various free vibration mode shapes are given.

6.4-3 Sinitsyn, A. P., **An effective method for calculating earthquake resistance of gravity dams** (Effektivnyi metod otsenki seismostoikosti gravitatsionnykh plotin, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94,* 1974, 7-14.

The earthquake resistance of gravity dams is considered in a dynamic setting with base yield and cross-sectional deformation taken into account. The finite element method is taken as the basis of the solution. Dynamic stresses in the dam and maximal shear forces along its base are calculated. For tall dams additional shearing stresses due to seismic loads up to 10-12 kg/cm^2 are computed on the basis of pseudo-velocity spectra of the Parkfield earthquake in 1966. Conclusions are drawn about adequate earthquake resistance for gravity dams.

6.4-4 Korchinskii, I. L. and Petrov, A. A., **Calculation of seismic loads on elongated heavy structures including rotation about vertical axis** (Opredelenie seismicheskikh nagruzok v protyazhennykh massivnykh sooruzheniyakh s uchetom vrashcheniya vokrug vertikalnoi osi, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94,* 1974, 31-39.

Seismic loads on heavy structures are calculated taking into account torques due to eccentricities with respect to the centers of mass and stiffness of a structure as well as to the presence of torsional vibrations induced by a traveling seismic wave with wavelength comparable to the dimensions of the structure considered. Formulas for computing load distribution coefficients in cases of linear and torsional vibrations are derived.

6.4-5 Miller, W. R. and Amin, H. S., **Low-cycle fatigue in welds,** *Experimental Mechanics,* **15,** *6,* June 1975, 230-233.

Hourglass-shaped specimens were made from ASTM A-516, grade 55, steel plates which had been welded together. The specimens were manufactured so that the weld material was at the minimum section. The specimens were strain-cycled about zero mean strain, and the results were compared with tests conducted on specimens taken from the parent material. When the total strain range versus the cycles to failure was plotted on log-log coordinates, the curves for both the welded and the parent-material specimens had nearly the same slope; however, the curve for the welded specimens was displaced downward from that of the parent material. Thus, for a given strain range, the parent-material specimens had lives approximately six times greater than the welded specimens.

Two-level cumulative damage tests on the welded specimens indicate that using $\Sigma\ n/N = 1.0$ is reasonably accurate.

6.4-6 Shestakov, N. A., **Forced vibrations of noncircular cylindrical shells with open profile** (Vynuzhdennye kolebaniya nekrugovykh tsilindricheskikh obolochek otkrytogo profilya, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2,* 1975, 31–33.

Stresses and strains in shells are calculated. The solution is found by means of expansion according to the eigenfunctions of free vibrations of the shell. The method is quite simple and is especially effective in the simultaneous presence of several types of dynamic excitations.

6.4-7 Samolyanov, I. I., **Response of hyperbolic paraboloid shell to lateral loading** (Ustoichivost obolochki tipa giperbolicheskogo paraboloida pri deistvii poperechnoi nagruzki, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1,* 1975, 28–30.

The response of a shallow hyperbolic paraboloidal shell subjected to lateral loading uniformly distributed along its surface is investigated. The problem is solved in a linear setting using a variational method. Diagrams showing critical load values for shells of the above type are given.

6.4-8 Kartsivadze, G. N., **Seismic response of long bridge structures** (Seismicheskie kolebaniya protyazhennykh mostovykh sooruzhenii, in Russian), *Sbornik nauchnykh trudov VNII transportnogo stroitelstva, 67,* 1975, 41–46.

The problem of seismic response of long bridge structures is studied in the linear setting. A system of differential equations for the forced vibrations of the bridge due to nonsynchronous ground motion is solved.

● 6.4-9 Ranganath, S. and Clifton, R. J., **Finite deflection dynamics of elastic beams**, *International Journal of Solids and Structures,* **10**, *6,* June 1974, 557–568.

Solutions are obtained for the problem of an infinite elastic beam subjected to essentially constant velocity boundary conditions at one point of the beam. The effects of finite deflections, normal force, rotatory inertia and shear deformation are included. The equations of the problem are converted into nondimensional form and a perturbation approach is used to obtain a consistent approximation. Numerical solutions are obtained for the bending moment, shear force and the normal force for different velocities of impact. It is shown that the solution to the problem depends on a combined geometrical and material parameter, which does not vary significantly for compact sections, and a loading parameter, which determines the amplitude of the response. Finally the linear Timoshenko beam theory is shown to predict the bending moment and shear force extremely well even when the deflections are large enough to cause appreciable stretching of the centroidal axis.

● 6.4-10 Paz, M., Cassaro, M. A. and Stewart, S. N., **Seismic response for self-strained structures**, *Bulletin of the Seismological Society of America,* **64**, *6,* Dec. 1974, 1809–1824.

The seismic response of multistory buildings and other structural systems is affected by the existence of self-strains which may be induced by temperature gradients, mechanical actions, or prestraining. The fundamental dynamic properties such as natural frequencies and mode shapes are influenced by the presence of these strains. As a consequence, the response of a structure changes to the extent that the self-strains change its dynamic characteristics and to the extent that these characteristics are relevant in the interaction of a particular structure with a given ground motion.

This paper presents a detailed study of some simple structures such as beams and frames, the members of which are subjected to initial strains. The homogeneous differential equations of motion are expressed in terms of the stiffness, mass, and geometry matrices and a parameter accounting for the self-strain effect. The solution of the resulting eigenvalue problem is used to write the modal equations into which the desired ground motion is applied.

The final response is obtained from the appropriate shock spectrum and the application of the root-mean-square superposition technique. The disturbing action produced by the ground motion of the well-known El Centro earthquake of 1940 is applied to several structures in which the amount of self-strain is varied as a parameter.

● 6.4-11 Blakeley, R. W. G., Cooney, R. C. and Megget, L. M., **Seismic shear loading at flexural capacity in cantilever wall structures**, *Bulletin of the New Zealand National Society for Earthquake Engineering,* 8, *4,* Dec. 1975, 278–290.

An investigation is described of the effect of various combinations of the normal modes of vibration of cantilever shear wall structures on the maximum shears at flexural capacity. It is shown that the base shear can be much

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higher than would be derived by assuming a normal code lateral load distribution of sufficient magnitude to cause flexural yielding. The results of elastic normal mode response spectrum analyses of a 10-story building considering several structural variables are presented. The results are given in terms of envelope values of the ratio of maximum base shear at flexural capacity to that assuming a code lateral load distribution. The same effect is investigated with a series of step-by-step numerical integration dynamic analyses of cantilever wall structures responding inelastically to a range of earthquakes. On the basis of the results, suggestions are made for the shear design of cantilever walls.

● 6.4-12 Laura, P. A. A. and Duran, R., **A note on forced vibrations of a clamped rectangular plate,** *Journal of Sound and Vibration,* **42,** *1,* Sept. 8, 1975, 129-135.

Simple polynomial approximations and Galerkin's method are used to determine the response of a thin, elastic, rectangular plate clamped along the boundary and subjected to sinusoidal excitation. It also is shown that a one-term polynomial solution yields good accuracy in the case of a rectangular plate with simply supported edges.

● 6.4-13 Iyengar, R. N. *et al.,* **Seismic analysis of the ventilation stack for the Madras atomic power project,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 39-46.

This paper presents the dynamic earthquake analysis of the ventilation stack of the Madras atomic power project. Since no past data are available for the site, two suitable design basis strong-motion earthquakes were artificially generated. A nonstationary random process model was used to simulate the important expected characteristics of the earthquakes, such as the maximum acceleration, duration, number of zero crossings and rate of decay. The stack was treated as a cantilever with varying mass and moment of inertia. Detailed results are presented in the form of maximum bending moments and shear force at various sections, using the above-mentioned artificially generated records and records of the Dec. 11, 1967, Koyna earthquake.

● 6.4-14 Chandrasekaran, A. R. *et al.,* **Static and dynamic analysis of an arch dam,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 47-54.

An arch dam under static and dynamic loading is analyzed. In a symmetric valley, the dam can be adequately represented by four thick-shell finite elements. The dam is analyzed by simultaneously considering three components of ground motion, two horizontal and one vertical. The root-mean-square method for combining modes is shown to be inadequate for arch dams. A simpler procedure for combining modes is proposed. For earthquake loading, the top regions at the crown section and the quarter sections are critical.

● 6.4-15 Popplewell, N., **The response of box-like structures to weak explosions,** *Journal of Sound and Vibration,* **42,** *1,* Sept. 8, 1975, 65-84.

The finite element displacement method is used to predict the vibrations of box-like buildings induced by weak blast waves. The theory is the first to incorporate experimental data to describe comprehensively the complex distortions of the blast waves by flexible structures. Numerical computations performed for three typical medium-low buildings indicate that the effects of aerodynamic variations on the structure become more important as the strength of the blast increases. Wave distortions should not be neglected for nuclear blasts, although earlier work implies that this normally would be acceptable for the lower intensities associated with sonic booms from commercial supersonic aircraft. Other critical factors which govern the response are shown to be the orientation and dimensions of the building, while the influence of structural coupling is seen to vary appreciably with relative dimensions, edge constraints and load differentials of components.

● 6.4-16 Bradford, L. G. and Dong, S. B., **Elastodynamic behavior of laminated orthotropic plates under initial stress,** *International Journal of Solids and Structures,* **11,** 2, Feb. 1975, 213-230.

A finite element method of analysis of the vibrational and wave propagational characteristics is presented for a laminated orthotropic plate under initial stress. The plate may have an arbitrary number of bonded elastic orthotropic layers, each with distinct thickness,, density and mechanical properties; and the analysis is capable of treating a completely arbitrary three-dimensional state of initial stress. Biot's theory for incremental elastic deformations of a stressed solid forms the basis for this study. A homogeneous, isotropic plate under two different states of initial stress was analyzed, and the numerical results show excellent correlation with those from an exact solution. Further examples of a three-layer composite plate and a sandwich plate are offered to add some general insight into the physical behavior of such plates.

● 6.4-17 Van Dooren, R. and Bouc, R., **Two mode subharmonic and harmonic vibrations of a non-linear beam forced by a two mode harmonic load,** *International Journal of Non-Linear Mechanics,* **10,** *6,* 1975, 271-280.

The nonlinear transverse vibrations of a uniform beam, with ends restrained to remain a fixed distance apart and forced by a two mode function which is harmonic in time, are studied by a corresponding two-mode approach.

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The existence of subharmonic response of order 1/3 and harmonic response in the subharmonic resonance region of the forcing frequency is proved. Approximate solutions are found by Urabe's numerical method applied to Galerkin's procedure and by an analytical harmonic balance-perturbation method. Error bounds of the Galerkin approximations are given.

● 6.4-18 Taranath, B. S., **Analysis of interconnected open section shear wall structures,** *Journal of the Structural Division, ASCE,* **101,** *ST11,* Proc. Paper 11736, Nov. 1975, 2367–2384.

A study is made of three-dimensional behavior of open section shear walls subjected to lateral loads. Emphasis is placed on the warping behavior of the open section shear walls and interaction provided by bending and warping interconnecting floor slabs. Comparisons are made between the analytical results of the present method and those of a three-dimensional analysis in which warping is ignored. The order of magnitude of warping effects are such that to neglect them in the analysis of an open section shear wall system might lead to serious errors in the calculated stresses and consequent design of structures.

● 6.4-19 Jagadish, K. S., **The dynamic stability of tall structures subjected to vertical ground motion,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 285–288.

Some recent earthquake accelerograms have shown that the vertical component of ground motion may not be negligibly small. It is possible that tall structures are subjected to parametric excitation under the influence of fluctuating inertia loads in the vertical direction. This paper examines the parametric resonance in such structures. The occurrences of Mathieu and combination resonances due to sinusoidal inputs are studied. The regions of instability for a tall chimney are shown for illustration.

● 6.4-20 Thakkar, S. K. and Arya, A. S., **Response of fixed arches under seismic forces,** *The Journal of the Institution of Engineers (India),* **55,** *CI 5/6,* May 1975, 189–195.

The elastic response of fixed arches under seismic forces is studied for a wide range of geometrical and vibrational parameters. Parameters, such as shape, rise-span ratio, span-to-radius of gyration ratio, stiffness distribution, fundamental period, mass distribution, damping, and ground motions, are considered in order to determine their influence on earthquake response. From this study many specific results are derived concerning a number of significant modes, a comparison of the timewise and the root mean square response with the seismic-coefficient approach, the critical sections in the arch, and the contribution of the vertical component of ground motion to the total response.

● 6.4-21 Paz, M. and Wong, J., **Response of strained structures to time-phased seismic excitations,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 64, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

The response of structural systems to seismic excitation is affected by the presence of axial forces in the members as well as by the time-delayed arrival of the seismic wave at the various excitation points. The natural frequencies and other dynamic properties are influenced by the presence of axial forces. As a result, the response of the structure changes to the extent that the axial forces change its dynamic characteristics and to the extent that these characteristics are relevant in the interaction of the structure with a given earthquake.

This paper presents a parametric study of some simple structures whose members are subjected to initial axial forces simultaneous to the action of multiple time-phased seismic motion of the supports. The final response is obtained after solving the corresponding eigenvalue problem from the appropriate shock spectra and the application of the root-mean-square superposition technique. The disturbing action produced by the ground motion of the well-known El Centro earthquake of 1940 is applied to several structures in which the amount of the axial forces and the time phase of the excitation are varied parametrically.

6.4-22 Medetbekov, A., **Seismic vibrations of circular bars** (Seismicheskie kolebaniya krugovykh sterzhnei, in Russian), *Trudy Frunz. politekhnicheskogo instituta, 65,* 1974, 46–53.

Seismic response of circular bars is studied. A differential equation is obtained and solved using the free vibration modes of the bar. A direct computation of internal stresses due to seismic forces in the circular bar is given without calculating the seismic forces themselves.

6.5 Nondeterministic Dynamic Behavior of Linear Structures

6.5-1 Goloskokov, E. G. *et al.*, **Response of mechanical systems to nonstationary seismic excitation** (Reaktsiya mekhanicheskikh sistem na nestatsionarnoe seismicheskoe vozdeistvie, in Russian), *Dinamika i prochnost mashin, 22,* 1975, 3–5.

The behavior of structures subjected to nonstationary seismic excitation is investigated using multidimensional Markov processes. Numerical results are obtained for systems with one and two degrees-of-freedom.

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● **6.5-2** Kulkarni, A. M., Banerjee, J. R. and Sinha, P. K., **Response of randomly excited orthotropic sandwich plates,** *Journal of Sound and Vibration,* 41, *2,* July 22, 1975, 197-205.

The displacement response of randomly excited simply supported orthotropic sandwich plates is investigated analytically. The source of random excitation is assumed to be an ideal white noise uniformly distributed over the plate. The mean square response of the displacement is computed for various values of such nondimensional parameters as the damping ratio, the core shear stiffness, the core orthotropy, the face orthotropy and the aspect ratio. The results obtained are shown graphically and discussed.

6.6 Deterministic Dynamic Behavior of Nonlinear Structures

● **6.6-1** Aktan, A. E., Pecknold, D. A. and Sozen, M. A., **R/C column earthquake response in two dimensions,** *Journal of the Structural Division,* ASCE, **100,** *ST10,* Proc. Paper 10864, Oct. 1974, 1999-2015.

The earthquake responses of a spirally reinforced concrete column carrying a concentrated mass and subjected to the simultaneous action ("biaxial response") of both horizontal components of normalized 1940 El Centro, 1962 Taft, and 1971 Pacoima Dam accelerograms were studied. Two different masses, corresponding to initial elastic periods of 0.65 sec and 1.5 sec were considered. The column force-displacement characteristics were synthesized from idealized stress-strain properties for steel and confined and unconfined concrete, using a discretization of the column cross section combined with finite element techniques. Maximum displacements were significantly larger in biaxial response when the excitation was sufficiently intense in relation to the column strength to cause appreciable inelastic deformation. If planar analysis indicates inelastic response in a column resisting earthquake effects in both horizontal directions, the effects of the axial load ($P - \Delta$ effect) may be more critical and the required "ductility" may be larger than that based on planar analysis.

6.6-2 Masri, S. F., **Forced vibration of the damped bilinear hysteretic oscillator,** *The Journal of the Acoustical Society of America,* 57, *1,* Jan. 1975, 106-112.

An exact solution is presented for the steady-state motion of a sinusoidally excited single-degree-of-freedom system exhibiting bilinear hysteresis and subjected to viscous damping that may be different in the "elastic" region from the "yielded" region.

6.6-3 Mendelson, E. and Baruch, M., **Damped earthquake response of non-symmetric multi-storey structures,** *The Structural Engineer,* 53, *4,* Apr. 1975, 165-171.

The analysis of the damped and undamped earthquake response of nonsymmetric multistory structures is presented, with consideration of the foundation mass and partial restraint of the structure in the subgrade. The analysis is based on the continuous connection method using the normal modes of the structure. Proportional damping and constant damping are considered. A numerical example represents the influence of the damping, subgrade rigidity and foundation mass on the response.

6.6-4 Snowdon, J. C., **Vibration of simply supported rectangular and square plates to which lumped masses and dynamic vibration absorbers are attached,** *The Journal of the Acoustical Society of America,* 57, *3,* Mar. 1975, 646-654.

A theoretical description is given of the forced vibration of internally damped rectangular and square plates with simply supported boundaries. Calculations are presented that illustrate the frequency dependence of the force transmissibility and driving-point impedance of the plates. Both central and noncentral driving forces are considered; the reduction in plate vibration that results from the attachment of central loading masses and dynamic vibration absorbers is demonstrated. The way in which the natural frequencies of the plates are moved to progressively lower frequencies as the loading mass is increased is explained and illustrated. Conditions of optimum tuning and damping for the dynamic absorbers are described and design data are tabulated. The resilient mounting of massive vibrating items on the plates is also considered. The vibrating items are supported via four damped springs that are symmetrically, but otherwise arbitrarily, located with respect to the plate centers. Advantageous reductions in force transmissibility are shown to result from judicious choice of spring locations that enable the excitation of several modes of plate vibration to be avoided.

6.6-5 Ivovich, V. A., **Effects of random, harmonic and polyharmonic excitations on nonlinear systems** (Vliyanie sluchainykh, garmonicheskikh i poligarmonicheskikh vozmushchenii na nelineinuyu sistemu, in Russian), *Trudy TsNII stroitelnikh konstruktsii, 34,* 1974, 17-35.

Nonlinear vibrations of elastic systems described by a single generalized coordinate are investigated. Fundamental differential equations are obtained for vibrations of membranes with rectangular and circular contours in the plane and for vibrations of isolated systems. The geometrical nonlinearity of the systems caused by changes in stresses with small finite deflections during vibration is taken into account.

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6.6-6 MacBain, J. C. and Genin, J., **Energy dissipation of a vibrating Timoshenko beam considering support and material damping**, *International Journal of Mechanical Sciences*, 17, *4*, Apr. 1975, 255-265.

This paper studies the effect of boundary conditions, via end-fixity and damping, on the overall damping capacity of a flexibly supported cantilever under the condition of steady-state vibrations. The effect of the beam's length-to-depth ratio is accounted for through the use of Timoshenko beam theory. The cases of a cantilever having a flexible viscously damped support and a cantilever-support system having a combination of structural support damping and beam material damping are focused upon. Comparisons are made with the results of other investigators.

● 6.6-7 Bertero, V. V. and Popov, E. P., **Hysteretic behavior of reinforced concrete flexural members with special web reinforcement**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 316-326.

An investigation was conducted to (1) obtain information on the strength, ductility, energy absorption and dissipation capacities, mechanisms of stiffness and energy degradation, and mechanisms of failure occurring in the critical regions of reinforced concrete members when subjected to cycles of high shear force reversals such as those expected under severe earthquake-like conditions; (2) investigate the effectiveness of different web reinforcements in improving the hysteretic behavior of these members; (3) use the obtained information for formulating realistic mathematical models; and (4) assess the aseismic design implications of the information obtained and formulate recommendations for improving code provisions.

To achieve the above objectives, a series of experimental and analytical investigations was carried out. Only the results obtained in four series of experiments conducted on seven similar specimens are discussed in this paper. Descriptions of the specimens, the testing procedure and the main results are presented. In addition, recommendations for improving the aseismic design of reinforced concrete members are formulated.

● 6.6-8 Wu, R. W.-H. and Witmer, E. A., **The dynamic responses of cylindrical shells including geometric and material nonlinearities**, *International Journal of Solids and Structures*, **10**, *2*, Feb. 1974, 243-260.

The methods of finite element analysis are applied to the problem of large deflection elastic-plastic dynamic responses of cylindrical shells to transient loading. Assumed-displacement quadrilateral finite elements of a cylindrical panel are used to idealize the cylindrical shell structure. The formulation is based upon the principle of virtual work and D'Alembert's principle. A direct numerical integration procedure is employed to solve the resulting equations of motion timewise. The present predicted dynamic responses of an explosively loaded clamped cylindrical panel are compared with other independent predictions and with experimentally measured responses; very good agreement is observed.

● 6.6-9 Pecknold, D. A., **Inelastic structural response to 2D ground motion**, *Journal of the Engineering Mechanics Division, ASCE*, **100**, *EM5*, Proc. Paper 10846, Oct. 1974, 949-963.

According to current seismic design philosophy, structures are allowed, for economic reasons, to undergo deformations well into the inelastic range when subjected to a strong-motion earthquake. Results presented show that the simultaneous action of both horizontal components of ground motion produces significantly larger displacements than those produced by a single component for stiff structures proportioned according to the Uniform Building Code. The magnification of response due to biaxial motion depends primarily on the initial fundamental elastic period of the structure and on the amount of inelastic deformation which a single component of ground motion would produce. The interaction of gravity loads with these increased displacements can cause the P-Δ effect to be more critical than for one-dimensional ground motion. The numerical results presented are for a series of single- and three-story structures with elasto-plastic uniaxial restoring force characteristics.

● 6.6-10 Irvine, H. M., **Statics and dynamics of cable trusses**, *Journal of the Engineering Mechanics Division, ASCE*, **101**, *EM4*, Proc. Paper 11506, Aug. 1975, 429-446.

The top and bottom chords consist of continuous prestressed cables which are anchored at each end and between which numerous vertical light rigid spacers are placed. When used in arrays, the cable truss has proved to be a useful structural element by which the roofs of buildings of large span may be supported. Following a general derivation of the equations of vertical equilibrium and compatibility, attention is focused on those cable trusses that are either biconvex or biconcave and initially symmetrical. This essentially removes the nonlinearities that would characterize the asymmetrical truss response to applied vertical load and the analysis is simplified considerably. Detailed solutions are presented for the static response of a symmetrical parabolic truss to a point load, a uniformly distributed load, and a triangular loading block. In the dynamic analyses an investigation is made of the natural frequencies and modes of vertical vibration; the theories are applied to roofs both rectangular and circular in plan.

6.6-11 Pollner, E., Tso, W. K. and Heidebrecht, A. C., **Analysis of shear walls in large-panel construction**, *Cana-*

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dian Journal of Civil Engineering, 2, 3, Sept. 1975, 357–367.

A study is made of the behavior of shear wall systems made from large precast panels. Three commonly used wall arrangements are studied. The loading consists of monotonically increasing lateral uniform load. Realistic vertical joint and connecting lintel characteristics are incorporated into the mathematical model. A step-by-step calculation technique is used to study the vertical joint and lintel behavior and its effect on the overall stiffness degradation of the system as load increases. The effect of flexible foundation on the overall behavior also is studied.

● 6.6-12 Morris, N. F., **Dynamic response of cable networks,** *Journal of the Structural Division, ASCE*, **100**, *ST10*, Proc. Paper 10895, Oct. 1974, 2091–2108.

A method is presented for calculating the nonlinear dynamic response of three-dimensional cable networks. Large changes in geometry are considered in the analysis. The method is applied to three typical cable networks, a planar network, a hyperbolic roof net, and a general three-dimensional layered system. Static response, mode shapes and frequencies, and the development of frequency-amplitude curves are all examined. Agreement with experimental data appears to be quite good.

● 6.6-13 Gergely, P., Stanton, J. F. and White, R. N., **Behavior of cracked concrete nuclear containment vessels during earthquakes,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 512–518.

When an earthquake occurs simultaneously with the buildup of pressure in a reinforced concrete nuclear containment shell, seismic shear forces are transmitted across the horizontal crack planes in the cylindrical wall of the shell by interface shear transfer (combination of shear friction and aggregate interlocking), by dowel action of the bars, and by diagonal bars if they are used. One important question in the design of such vessels is whether the diagonal bars are necessary.

In the experimental portion of the current investigation, several types of tests were conducted to study the load-slip characteristics of interface shear transfer under high intensity cyclic loading. In some cases external bars provided the clamping action of reinforcement; in more recent tests large-diameter embedded bars were used.

The analytical part of the investigation is summarized in this paper. A representative load-slip curve was used in the analyses to assess the intensity of the stresses and deformations and to study the importance of the variables as an aid in planning future tests. The results presented are, therefore, only preliminary.

● 6.6-14 Taya, M. and Mura, T., **Dynamic plastic behavior of structures under impact loading investigated by the extended Hamilton's principle,** *International Journal of Solids and Structures*, **10**, 2, Feb. 1974, 197–209.

The authors propose the use of the extended Hamilton principle to investigate the dynamic plastic behavior of a beam or a plate under impact loading. Material is assumed to be rigid perfectly plastic. The impact loading is given in the form of initial velocity. Good agreement between the authors' numerical solutions and experimental results found by Parkes and Jones indicates that the proposed variational method is a powerful approximation method for the dynamic plasticity analysis. The effect of strain-rate sensitivity on the permanent deflection of a plate is investigated in some detail. Instead of nonlinear differential equations, nonlinear algebraic equations are solved in the proposed method.

6.6-15 Kurobane, Y. and Konomi, M., **Some simple S-N relationships in fatigue of tubular K-joints,** *Transactions of the Architectural Institute of Japan, 212*, Oct. 1973, 9–22.

In this report the fatigue strength of tubular K-joints is expressed in terms of a ratio of the fatigue strength to the static strength, with which *S-N* diagrams are established for all the joints tested by the authors. The results show that one *S-N* curve is a good approximation to represent the fatigue behavior of various types of tubular K-joints supporting the foregoing statement. Since the patterns of static and fatigue failures vary with the joint types, care must be taken of the limitations within which each *S-N* curve is applicable. These limitations are discussed also in the following section. It is hoped that the *S-N* diagrams proposed here will provide a better background for the proper design of K-joints.

● 6.6-16 Srirangarajan, H. R., Srinivasan, P. and Dasarathy, B. V., **Ultraspherical polynomials approach to the study of third-order non-linear systems,** *Journal of Sound and Vibration*, **40**, 2, May 22, 1975, 167–172.

In this study, the Krylov-Bogolinbov-Mitropolskii-Popov asymptotic method is used to determine the transient response of third-order nonlinear systems. Instead of averaging the nonlinear functions over a cycle, they are expanded in ultraspherical polynomials and the constant term is retained. The resulting equations are solved to obtain the approximate solution. A numerical example is considered and the approximate solution is compared with the digital solution. The results show that there is good agreement between the two values.

● 6.6-17 Srirangarajan, H. R. and Dasarathy, B. V., **Study of third-order non-linear systems—Variation of parameters**

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approach, *Journal of Sound and Vibration*, **40**, *2*, May 22, 1975, 173–178.

In this paper, the transient response of a third-order nonlinear system is obtained by first reducing the given third-order equation to three first-order equations by applying the method of variation of parameters. On the assumption that the variations of amplitude and phase are small, the functions are expanded in ultraspherical polynomials. The expansion is restricted to the constant term. The resulting equations are solved to obtain the response of the given third-order system. A numerical example is considered to illustrate the method. The results show that the agreement between the approximate and digital solution is good thus justifying the approximation.

● 6.6-18 Anderson, G. L., **The method of averaging applied to a damped, non-linear system under harmonic excitation,** *Journal of Sound and Vibration,* **40**, 2, May 22, 1975, 219–225.

To provide a more suitable analysis of the harmonically excited motion of certain nonlinear systems, the method of slowly varying phase and amplitude is modified to account for the presence of a linear damping term in the nonlinear differential equation of motion. In the application of the technique described here, the assumption of very small linear damping has been relaxed. Approximate expressions for the amplitude and phase of the motion near a state of internal resonance are derived, and the frequency-amplitude relation for stationary oscillations is determined. It is shown that, in the limit of very small linear damping, the frequency-amplitude relation reduces to one derived by the more familiar version of the method of averaging.

● 6.6-19 Benveniste, Y. and Aboudi, J., **The dynamic response of a laminated plate under large deformations,** *Journal of Sound and Vibration,* 38, *4*, Feb. 22, 1975, 425–436.

The effective stiffness theory, which represents a layered composite as a higher-order continuum with microstructure, is employed to describe the linear as well as the nonlinear dynamic response of a laminated plate. The plate is subjected to normal time-dependent tractions in the direction of the layering and both small and large deformations are considered. For the case of infinitesimal deformations the results obtained are compared with those based on the complete theory of elasticity. The coupled nonlinear hyperbolic differential equations which govern the response of the plate under large deformations are solved and the results are contrasted with those of the linear plate.

● 6.6-20 Lord, J., Hoerner, J. B. and Zayed, M., **Inelastic dynamic analysis of steel structures,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **8**, *4*, Dec. 1975, 273–277.

This paper updates a previously described analytical approach that uses computer technology to investigate the time-dependent material nonlinear behavior of two-dimensional moment-frame, truss-frame, and braced-frame steel structures during significant excursions into the post-elastic range. The approach includes considerations for energy analysis, element buckling, stable or unstable mechanism formation, yield capacity reduction resulting from interaction of axial load and bending moment, stiffness degradation, P-δ effects, viscous damping, joint panel zone deformation, and also incorporates a suitable element load deformation relationship. The computer program NLDYN2, which incorporates this approach, has been implemented successfully on many steel structures, ranging from 60-story moment frames to braced frames having aspect ratios of up to 10.

● 6.6-21 Biot, M. A., **Buckling and dynamics of multilayered and laminated plates under initial stress,** *International Journal of Solids and Structures,* **10**, *4*, Apr. 1974, 419–451.

The continuum mechanics of multilayered plates under initial stress is developed to include the case where some or all of the layers are constituted by thinly laminated materials with couple stresses. It is applicable to problems of buckling, dynamics and vibrations. This includes the evolution of viscoelastic creep, buckling and vibration absorption. Results are obtained in two forms. One is derived from a rigorous analysis using the general theory of incremental deformations; the other provides drastic simplifications while retaining essential physical features which are consequences of the continuum behavior. Use of a particular definition of incremental stress is emphasized which is of special advantage in the type of problems under consideration. Corresponding variational principles also are formulated. Exact and approximate theories are compared both analytically and numerically. Excellent agreement is obtained.

● 6.6-22 Rangacharyulu, M. A. V. and Dasarathy, B. V., **Non-linear systems with quadratic and cubic damping—An analytical approach,** *Journal of Sound and Vibration,* 38, *1*, Jan. 8, 1975, 9–13.

The possible equivalence of second-order nonlinear systems having quadratic and cubic damping with third-order linear systems is studied in this paper. It is shown that this equivalence can be established through transformation techniques under certain constraints on the form of the nonlinearity of the given system.

● 6.6-23 Goldberg, J. and Koenig, H. A., **The non-linear dynamic response of an impulsively loaded circular plate**

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with a central hole, *International Journal of Solids and Structures*, **11**, *9*, Sept. 1975, 985–997.

A numerical method, called direct analysis, is described and applied to solve the problem of a plate undergoing a large impulsive load. For generality, an expanded, nonlinear form of the equations of motion is used and shear correction and rotatory inertia are considered. The wave speeds are calculated from the nonlinear equations and appropriate boundary conditions are applied so that reflected waves are included. The results for two types of step loading pulses are presented and compared with previously presented solutions. The response of the plate is discussed and conclusions as to the effects of the nonlinearities are given.

● **6.6-24** Singh, P. N. and Ali, S. M. J., **Non-linear vibration of a moderately thick shallow clamped arch,** *Journal of Sound and Vibration*, **41**, 3, Aug. 8, 1975, 275–282.

Large amplitude flexural vibrations of a moderately thick arch are studied. The material of the arch is assumed to be homogeneous, isotropic and linearly elastic. Governing equations are derived by the variational method. Values of the period for different amplitudes for arches with built-in ends are computed by numerical integration. Phenomena like dynamic buckling, transition from a slightly curved beam to a shallow arch, etc., are discussed. Results computed for the limiting case of a thin beam are in good agreement with the existing results.

● **6.6-25** Mahalingam, S., **The response of vibrating systems with Coulomb and linear damping inserts,** *Journal of Sound and Vibration*, **41**, *3*, Aug. 8, 1975, 311–320.

The concept of internal receptance described in an earlier paper is used in the analysis of the response of vibrating systems with one or more discrete damping inserts. In the case of dry friction damping, "linearized" expressions for force and displacement are assumed. The lack of a receptance function for such a damper is overcome by replacing it with an equivalent displacement excitation source. When the inserts are linear dampers (viscous, hysteretic, etc.) or damped sub-systems, the solution is by means of a receptance synthesis. In both cases the response is determined with the aid of the internal receptances and transfer ratios of the primary system.

● **6.6-26** Sridhar, S., Mook, D. T. and Nayfeh, A. H., **Nonlinear resonances in the forced responses of plates, Part I: Symmetric responses of circular plates,** *Journal of Sound and Vibration*, **41**, 3, Aug. 8, 1975, 359–373.

The dynamic analog of the von Karman equations is used to study the symmetric response of a circular plate to a harmonic excitation when the frequency of the excitation is near one of the natural frequencies. The response is expressed as an expansion in terms of the linear, free-oscillation modes, and its amplitude is considered small but finite. The method of multiple scales is used to solve the nonlinear equations governing the time-dependent coefficients in the expansion. It is shown that, in general, when there is no internal resonance (i.e., the natural frequencies are not commensurable), only the mode having a frequency near that of the excitation is strongly excited (i.e., is needed to represent the response in the first approximation). A clamped, circular plate is used as a numerical example to show that, when there is an internal resonance, more than one of the modes involved in this resonance can be strongly excited; moreover, when more than one mode is strongly excited, the lower modes can dominate the response, even when the frequency of the excitation is near that of the highest mode. This possibility was not revealed by any of the earlier studies based on the same governing equations.

● **6.6-27** Szemplinska-Stupnicka, W., **A study of main and secondary resonances in non-linear multi-degree-of-freedom vibrating systems,** *International Journal of Non-Linear Mechanics*, **10**, *6*, 1975, 289–304.

A uniform study of all types of resonances that can occur in a nonlinear, dissipative multidegree-of-freedom systems subject to sinusoidal excitation is presented. The theoretical investigation is based on a harmonic or multiharmonic solution and the Ritz method. The new approach suggests that the nonlinear normal mode shape or the so-called "coupled" nonlinear mode shapes are those which are retained in resonance conditions, no matter what type of resonance–main, or secondary, periodic or almost-periodic.

By introducing the concept of nonlinear normal coordinates, the response of an n-degree-of-freedom system is described, to a satisfactory degree of accuracy, by a single coordinate in the case of main or secondary-periodic resonance, or by p coordinates in the case of almost-periodic (combination) resonance with p harmonic components.

Numerical examples indicate good agreement of theoretical and analog computer results and illustrate considerable discrepancies between resonance curves calculated by the commonly used "single linear mode approach" and the suggested "single nonlinear mode approach".

● **6.6-28** Nowinski, J. L., **Some static and dynamic problems concerning non-linear behavior of plates and shallow shells with discontinuous boundary conditions,** *International Journal of Non-Linear Mechanics*, **10**, *1*, Feb. 1975, 1–14.

Berger's field equations are generalized to dynamic phenomena in anisotropic plates and shallow shells, the anisotropy being either of cylindrically orthotropic or

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rectilineariy orthotropic type. Under the assumption that the rim of the structure is prevented from inplane motions, explicit equations for the coupling parameter are given. The method of solution in the dynamic case is illustrated by an example involving isotropy and original axial symmetry of the structure. It is shown that for the nonlinear oscillations of built-in circular plates a close agreement is reached with the results obtained by means of the von Karman field equations and a different coordinate function. The procedure suggested for solution of dynamic problems associated with the discontinuities of the boundary conditions is discussed and illustrated in an isotropic case involving a circular plate partially simply supported and partially clamped at the periphery.

A numerical example is given concerning static behavior of an infinite isotropic strip uniformly loaded and simply supported along the edges except for two symmetrically situated built-in segments. The dependence of the average moment of clamping on the width of the built-in segments, as well as on the load intensity for a fixed width of the segments is displayed on graphs.

● 6.6-29 Tso, W. K., **Induced torsional oscillations in symmetrical structures,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3,** *4,* Apr.–June 1975, 337–346.

A study is made of the torsional-lateral motions of nonlinear symmetrical structures subjected to lateral ground motion. The torsional and lateral response of a single mass symmetrical system subjected to sinusoidal ground motion is investigated. The load-displacement relationship of the resisting elements is assumed to be weakly nonlinear and of a softening type. It is shown that nonlinear coupling exists between the lateral and rotational motions. For sinusoidal lateral response, the torsional motion equation can be cast in the form of a Mathieu equation. The likelihood of induced torsional response is then studied in terms of unstable regions in the parametric amplitude-frequency parameter space. The implication of this type of nonlinear torsional-lateral coupling to the responses of real symmetrical structures subjected to actual earthquake ground motion is then discussed.

● 6.6-30 Anderson, J. C. and Johnston, S. B., **Seismic behaviour of above-ground oil pipelines,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3,** *4,* Apr.–June 1975, 319–336.

The dynamic behavior of above-ground oil pipelines, allowed to slide back and forth on intermediate supports during strong-motion earthquakes, is studied. This sliding is resisted by friction between the pipe and the top of the support. The main objective of the study is to determine the effect of this nonlinear friction on both the static and dynamic stresses in the pipe. The study also considers the influence of other critical parameters, such as pipeline configuration, seismic wave velocity, initial temperature differential and internal pressure, and ground motion characteristics. Results show that the critical bending moments in the pipe occur during the static loading and that with seismic excitation these moments tend to shake down as the pipe moves to a more stress-free configuration. It is shown that the use of sliding friction can be an effective means of dissipating seismic energy and thereby damping the dynamic response of the pipeline, even for low values of the coefficient of friction.

● 6.6-31 Symonds, P. S. and Chon, C. T., **Bounds for finite deflections of impulsively loaded structures with time-dependent plastic behavior,** *International Journal of Solids and Structures,* **11,** *4,* Apr. 1975, 403–423.

The paper shows that upper bounds on deflections of an impulsively loaded structure whose behavior in the plastic range is strain-rate dependent may be obtained by an application of the theorem of minimum potential energy, with results valid for finite deflections and strains. The concepts of extremal path behavior in strain-time space, due to Ponter, are used in order to provide unique definitions of strain energy and complementary energy for the path-dependent material. The theorems are illustrated by examples of fully constrained beams in which deflections of the order of the beam thickness lead to large forces of membrane type.

● 6.6-32 Nagarajan, S. and Popov, E. P., **Plastic and viscoplastic analysis of axisymmetric shells,** *International Journal of Solids and Structures,* **11,** *1,* Jan. 1975, 1–19.

A general formulation of large deformation analysis of plastic and viscoplastic problems is presented first. The equilibrium equations are derived from an incremental variational formulation using the Lagrangian mode of description of motion. The symmetric Piola-Kirchhoff stress and Lagrangian strain are used in all the constitutive relations. Using degenerate isoparametric elements, permitting relaxation of the Kirchhoff-Love hypothesis, the procedure is specialized for the finite element analysis of shells of revolution subjected to axisymmetric loading. A modified incremental method, which applies an equilibrium correction at each step, is used for the solution of the linearized incremental equilibrium equations. Two approaches are presented for adapting the viscoplasticity formulation to provide inviscid plasticity solutions—one involving the extrapolation of results as the viscosity coefficient tends to infinity, and the other in which plasticity solutions are obtained by using time as the artifice in the viscoplastic analysis until equilibrium states are achieved at each succeeding load level. A detailed study of the nonlinear behavior of a torispherical pressure vessel is presented to illustrate the effectiveness of the numerical techniques.

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● 6.6-33 Anderson, J. C., **Seismic behavior of K-braced framing systems**, *Journal of the Structural Division, ASCE*, **101**, *ST10*, Proc. Paper 11636, Oct. 1975, 2147–2159.

Three ten-story three-bay structures having K-braced framing systems are designed for seismic loads according to building code requirements. Members are proportioned by standard allowable stress procedures. The frames are subjected to strong ground motion and the inelastic response of the three systems is evaluated and compared. Results show that increased ductility requirements occur in regions adjacent to discontinuities in lateral stiffness. The addition of an outrigger truss at the top of the frame tends to force more of the inelastic deformation into the girders and bracing rather than the columns. The fully braced systems are very effective in controlling lateral displacement.

● 6.6-34 Krawinkler, H., Bertero, V. V. and Popov, E. P., **Shear behavior of steel frame joints**, *Journal of the Structural Division, ASCE*, **101**, *ST11*, Proc. Paper 11717, Nov. 1975, 2317–2336.

The load-deformational response of beam-column joints in moment-resisting steel frames, subjected to severe lateral actions, has been studied experimentally and analytically. The investigation showed that joints per se are elements with large energy dissipation capacity, exhibiting a high reserve strength beyond first yielding, large ductility, and stable hysteretic behavior. A trilinear mathematical model is proposed for the joint response that compares well with the experimental results. Design recommendations are given, based on strength and stiffness considerations. The effects of axial loads on the columns and shear stiffeners are investigated and included in the mathematical models and design recommendations. It is hoped that the results of the reported investigation will contribute to a better prediction of the static and dynamic characteristics of frames. These characteristics are strongly affected by the joint response, and joints need to be included as finite deformable elements in a realistic frame analysis.

● 6.6-35 Celebi, M., **Hysteretic behaviour of reinforced concrete beams under influence of shear and bending**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 375–380.

It is pointed out that shear pinching is an important phenomenon that influences energy absorption and stiffness degradation. However, an actual, representative model of a shear-pinched hysteresis loop has not yet been put forward. For purposes of inelastic analysis, Clough's degraded stiffness model, or the mathematical model created by incorporating material properties such as the Bauschinger effect in reinforcing steel, has been used. In this paper, based on experimental results, a new model using Ramberg-Osgood hysteresis loops is proposed.

● 6.6-36 Bertero, V. V., Mahin, S. A. and Hollings, J., **Response of a reinforced concrete shear wall structure during the 1972 Managua earthquake**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 315–324.

The 1972 Managua earthquake was a severe test of modern earthquake-resistant design and construction procedures. This paper examines the behavior of the 18-story reinforced concrete Banco de America building, which performed exceptionally well during the earthquake. Although the building suffered some structural and nonstructural damage, its large, symmetrically located, coupled shear walls limited this damage to levels significantly below those observed in more flexible structures.

Several linear elastic and nonlinear analyses were conducted to evaluate the building's behavior and determine the probable cause of the observed damage. The effects of biaxial ground motions, foundation flexibility, and ground motion characteristics were considered in the elastic investigations. To get a better idea of the dynamic behavior of the principal lateral force-resisting system considered in the design, nonlinear analyses were performed for the coupled shear wall cores as constructed and for the idealized case where the coupling girders were assumed to have unlimited ductility. The principal design deficiency was the low shear strength of the coupling girders. However, the nonlinear results indicated that had these girders been able to develop their flexural capacity, they would have suffered many reversals, and the shear walls would have been subjected to undesirable states of stresses. The analytical results as well as the building's performance demonstrated that buildings with slender coupled shear walls combined with ductile moment-resisting frames offer excellent protection against severe seismic excitations, minimizing nonstructural damage while providing several lines of defense in the event of localized failure. Design and repair recommendations are offered.

● 6.6-37 Chandra, B. and Prakash, R., **Inelastic behaviour of reinforced concrete structures during earthquakes**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 325–330.

Lateral load-deflection characteristics of simple reinforced concrete frames are studied to examine the earthquake resistance of such structures. It is shown that inelastic behavior may effect only a limited reduction in earthquake response. Steel is important for the earthquake-resistant design of structures since the strain ductility of steel controls the deformability of a structure in the inelastic range.

● 6.6-38 Mahin, S. A. and Bertero, V. V., **Interpretation of damages to the Charaima Building and their significance regarding present methods of seismic analysis and**

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design, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 297–306.

The seismic response characteristics of the eleven-story Charaima apartment building, which partially collapsed during the 1967 Venezuelan earthquake, are examined. The elastic dynamic characteristics and response time histories of the entire building for various combinations of slab, partition and foundation stiffnesses were evaluated in order to identify the general behavior of the building and its sensitivity to the modeling assumptions. More realistic analyses were performed with a computer program developed to model the inelastic dynamic behavior of reinforced concrete buildings, including member failure. The building frame, identified by the elastic results as initiating the collapse, was studied. These nonlinear analyses were used to investigate the effect of slab stiffness and ground motion characteristics on the seismic behavior of the building as it was constructed and where members were assumed to have unlimited ductility capacities. While both elastic and inelastic analyses identified failure mechanisms compatible with the observed damage, this was a consequence of the early brittle failure. Had the buildings failed in a more ductile manner, it is doubtful that the elastic results would have identified the correct failure mechanism. Furthermore, estimates of story shears, drifts and inelastic deformations based on elastic analyses are not reliable. The investigation emphasizes the importance of explicitly accounting for both strength and ductility in design, analysis and construction, since the building failed only where the structural system forced inelastic deformations to develop in nonductile members.

● 6.6-39 Sun, C. T. and Chattopadhyay, S., **Dynamic response of anisotropic laminated plates under initial stress to impact of a mass**, *Journal of Applied Mechanics*, **42**, Series E, 3, Sept. 1975, 693–698.

The central impact of a mass on a simply supported laminated composite plate under initial stress is investigated. The contact force and the dynamic response of the plate are obtained by solving a nonlinear integral equation. The energy transferred from the mass to the plate during impact is also obtained by use of a normalized contact force. It is found that a higher initial tensile stress elevates the maximum contact force, but reduces the contact time, the deflection, and the stresses. It is also noted that a higher tensile initial stress results in less energy transfer from the striking mass to the plate.

● 6.6-40 Yoshimura, K., **Inelastic behavior of steel H-shape columns subjected to repeated bending**, *Memoirs of the Faculty of Engineering, Kyushu University*, **34**, 3, Feb. 1975, 157–193.

As pointed out from many experimental studies on steel structures, when columns of tested frames or structural subassemblages are subjected to high axial compression and alternately repeated lateral loads, the maximum loads which can be carried by the frames or subassemblages are increased gradually with the repetition of cycles.

In this paper, in order to examine whether or not such an increase of the maximum load-carrying capacity of steel structures due to the repetition of cycles actually can be expected, dynamic response analyses of such structures are carried out.

● 6.6-41 Anderson, J. C. and Gurfinkel, G., **Seismic behaviour of framed tubes**, *International Journal of Earthquake Engineering and Structural Dynamics*, **4**, 2, Oct.-Dec. 1975, 145–162.

A framed tube, consisting of closely spaced columns connected by deep spandrel beams, is designed in reinforced concrete for building code loads. The members of the frame are proportioned using strength concepts. A planar model of the tube is developed and its behavior is compared to that of the three-dimensional structure. The planar model is then used to evaluate the inelastic behavior of the framed tube when subjected to strong ground motion. The effects of the finite element discretization and the ground motion characteristics are investigated. Results show that ductility requirements of the spandrel beams are minimum at the top and maximum at the bottom of the tube. Ductility requirements in the columns are well controlled and are within acceptable limits. Participation of the higher modes of vibration is significant and requires increasing damping. It also is shown that the increased stiffness due to finite member sizes at a joint cannot be neglected.

● 6.6-42 Lockhart, D. and Amazigo, J. C., **Dynamic buckling of externally pressurized imperfect cylindrical shells**, *Journal of Applied Mechanics*, **42**, Series E, 2, June 1975, 316–320.

The dynamic buckling of imperfect finite circular cylindrical shells subjected to suddenly applied and subsequently maintained lateral or hydrostatic pressure is studied using a perturbation method. The geometric imperfections are assumed to be small but arbitrary. A simple asymptotic expression is obtained for the dynamic buckling load in terms of the amplitude of the Fourier component of the imperfection in the shape of the classical buckling mode. Consequently, for a small imperfection, there is a simple relation between the dynamic buckling load under step-loading and the static buckling load. This relation is independent of the shape of the imperfection.

● 6.6-43 Tseng, W. S. and Penzien, J., **Seismic response of long multiple-span highway bridges**, *International Journal*

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of Earthquake Engineering and Structural Dynamics, 4, *1*, July–Sept. 1975, 25–48.

Nonlinear seismic responses are described for three prototype, long, multiple-span, reinforced concrete, modern highway bridge structures, namely the 5/14 South Connector Overcrossing and the curved Figueroa Street Undercrossing as designed by the California Dept. of Transportation, and a straight version of the Figueroa Street Undercrossing. The analytical seismic responses are discussed and correlated with the apparent prototype behavior experienced during the San Fernando, California, earthquake of Feb. 9, 1971. In particular, the causes of collapse of the 5/14 South Connector Overcrossing are identified and examined. Finally, based on parameter studies of the seismic responses of these structures, general conclusions and recommendations related to seismic design methodology are presented.

● 6.6-44 Kallaby, J. and Millman, D. N., **Inelastic analysis of fixed offshore platforms for earthquake loading,** *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2357, May 1975, 215–226.

Fixed offshore structures in seismic areas may be subject to intensive ground shaking causing the platform to undergo deformations well into the inelastic range. This paper presents a procedure that may be used to account for such inelastic behavior using an investigation of a major steel platform for illustration. A post-buckling capacity curve for bracing that may undergo column buckling is presented based on tests carried out in 1974.

● 6.6-45 Bouwkamp, J. G., **Buckling and post-buckling strength of circular tubular sections,** *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. I, Paper No. OTC 2204, May 1975, 583–592.

Results of axial load tests carried out on (8 5/8 in. x 0.219 in.) seamless and 12 3/4 in. x 0.250 in.) electric-weld Grade B line-pipes with slenderness ratios between 40 and 120 agreed reasonably well with predicted load values (using the tangent-modulus expression). Axial deformations prior to buckling were nonlinear. Local plastic buckling caused a drastic reduction of the post-buckling strength. Results indicate that an offshore tower under lateral loads can deform under ultimate conditions significantly more than a linear elastic analysis would indicate, thus increasing the earthquake resistance.

● 6.6-46 Mukhopadhyay, A., Itoh, Y. and Bouwkamp, J. G., **Fatigue behavior of tubular joints in offshore structures,** *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. I, Paper No. OTC 2207, May 1975, 613–622.

A comparative study of the potential fatigue behavior of tubular K-type joints is outlined in this paper using a cumulative damage approach. Theoretically derived fatigue prediction curves are used in the study. It is shown that under the same stress level the fatigue resistance increases proportionately with the yield strength for steels with yield strength lower than 60 ksi and remains approximately constant for steels with higher yield strength. Hence, an overall economy in terms of extended service life can be achieved.

● 6.6-47 Maison, J. R. and Holliday, G. C., **Comparison between predicted and experimentally determined low cycle fatigue life of welded tubular connections,** *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. 1, Paper No. OTC 2208, May 1975, 623–633.

A technique for prediction of fatigue failure of the tubular joints commonly found in offshore structures is described. The method is based upon fracture mechanics principles and crack growth data. A comparison is made between the fatigue failure of two K-joint models and the predictive method. A meaningful comparison is obtained for only one specimen as the other failed prematurely in a location not being monitored. Agreement was more qualitative than quantitative.

● 6.6-48 Wu, R. W. H. and Witmer, E. A., **Theoretical and experimental studies of transient elastic-plastic large deflections of geometrically stiffened rings,** *Journal of Applied Mechanics*, 42, Series E, *4*, Dec. 1975, 793–799.

Finite-element formulations have been derived for the large-deflection elastic-plastic dynamic responses of arbitrarily curved two-dimensional beam structures which may consist of hard-boned, multilayer, geometrically stiffened configurations. Experiments have been conducted for structural responses of geometrically stiffened, freely suspended, circular rings of 6061-T6511 aluminum alloy to intense explosive loading which induces large-deflection elastic-plastic transient and permanent deformations of the structure. Very good correlation of the measured permanent deformation and transient strain with theoretical predictions is demonstrated.

● 6.6-49 Dumanoglu, A. and Severn, R. T., **Dynamic frame-foundation interaction,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 40, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

Structure-foundation interaction of plane and asymmetric space frames is considered. Five-story models were built, with and without foundations, so that assessment of modes could be made against finite element and equivalent spring representations of foundations. Also a parametric

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computer study of foundation effects was made. Finally, and more importantly, models were subjected to five actual earthquake records, and the displacement response therefrom was satisfactorily compared with two methods of response analysis.

● 6.6-50 Pekau, O. A., **Behaviour of yielding soft-storey structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 72, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Framed structures with reduced-strength first stories have been studied under earthquake excitation. The importance of yield strength and bilinear behavior of the first story, and the effect of gravity P-Δ forces is examined. It is shown that sufficiently low first story strength allows elastic response of the superstructure but that maximum story shear generally exceeds the capacity of the soft story. Furthermore, elastic superstructures require almost ideal elasto-plastic first stories, a condition which may entail early P-Δ collapse.

● 6.6-51 Juhásová, E., **Dynamic unstability of the framed systems under the seismic loading,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 68, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The paper deals with the problem of the instability of the dynamic response of framed structural systems in the cases when the vibration of the structural systems is excited by the seismic motion of the soil foundation of the structures. First, attention is devoted to the seismic response of structures with open first stories. Experimental results of four alternative steel frame models are presented. The results of the theoretical solution are compared to the results of the experimental investigation from the point of view of the loss of stability of the vibration and the consequent failure of the structure.

● 6.6-52 Balint, E., **Vibration of prestressed concrete in the cracking phases,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 107, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Free and forced cyclic loads were applied to eccentrically prestressed beams and slabs into the plastic range and to failure. Measurements of the natural frequency and the critical damping ratio revealed the significance of three phases of cracking: initial, visible and terminal. Stress history mattered only in advanced cracking; when loads exceeded critical cracking limits, higher damping resulted from subsequent smaller loads. Increasing loads reduced the natural frequency; the reduction became significant when the load exceeded half the failure load. Frequency sweeps in forced vibration detected multiple harmonics which diminished in advanced phases of cracking. For increased damping, moderate precracking may be explored.

● 6.6-53 Paskaleva, I., **Nonelastic behaviour of some structural elements,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 99, 6. (For a full bibliographic citation see Abstract No. 1.2-8.)

Reinforced concrete columns with different cross sections, reinforcement and stirrups are tested for axial compression combined with reverse shearing and bending. Monolithic and prefabricated frames, formed by the same columns and slabs with and without infilling masonry, are tested for static horizontal reverse loading.

The influence of the reinforcement and axial compression in the columns on the strength and deformation characteristics is analyzed. Stiffness degradation and energy absorption in terms of the deformations and load history are determined.

The obtained results are used for investigation of the response of package lift-slabs and monolithic reinforced concrete frame buildings with infilling masonry in the nonelastic stage.

● 6.6-54 Krawinkler, H., Bertero, V. V. and Popov, E. P., **The beam-column joint—An important element in the seismic response of moment resisting steel frames,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 93, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

The load-deformational response of joints in frames subjected to severe lateral loading is discussed in detail. A mathematical model is presented for this response, and design recommendations are given for the required joint panel zone thickness based on strength and stiffness considerations. The influence of joint strength and deformation on the seismic response of frames is discussed considering the effects on the elastic strength and stiffness, the inelastic response, and the energy dissipation characteristics that can be greatly influenced by a proper distribution of inelastic deformations between beams and joints.

● 6.6-55 Uzümeri, S. M. and Seçkin, M., **Behaviour of joints and ductility of reinforced concrete frames,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 94, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

The results of an experimental study of the behavior of cast-in-place reinforced concrete beam-column joints subjected to slow load reversals simulating seismic loading are summarized. The ductility and inelastic energy dissipation characteristics of reinforced concrete frames are critically dependent on the performance of joints. The effect of the amount and type of joint stirrups on the joint confinement and beam steel anchorage are examined and the relationships between the joint behavior, stiffness deterioration and P-Δ effect are considered.

● **6.6-56** Badalian, R. A. *et al.*, **Investigating the earthquake resistance of multistory reinforced concrete buildings,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 120, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Discussed are the results of experimental and theoretical research of the dynamic characteristics of multistory buildings having spatial precast monolithic framework. Formulas are derived for determining the vibration periods of framed structures, taking into account the inelastic properties of the concrete. The results of dynamic and static tests of fragments of precast monolithic framework are discussed.

● **6.6-57** Hidalgo, P. and Clough, R. W., **Earthquake test behavior of a two-story reinforced concrete frame,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 90, 15. (For a full bibliographic citation see Abstract No. 1.2-8.)

A test of a single-bay, two-story reinforced concrete frame has been carried out using the 20 ft square shaking table facility, located in the Earthquake Simulator Lab. at the Univ. of California, Berkeley. The main objectives of this test were to obtain information on the behavior of such structures vibrating at amplitudes large enough to cause inelastic deformations, and to improve the currently available mathematical models for the analytical prediction of the structure's inelastic response to the earthquake excitation. This paper is concerned primarily with the latter purpose, that is, the analytical evaluation of the inelastic seismic response and its correlation with the measured performance.

● **6.6-58** Popov, E. P., Bertero, V. V. and Viwathanatepa, S., **Analytic and experimental hysteretic loops for r/c subassemblages,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 89, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

The hysteretic behavior of two reinforced concrete interior beam-column subassemblages is discussed. These half-scale subassemblages were made to correspond to the third-floor framing of a 20-story ductile moment-resisting frame which was designed using the strong column-weak girder approach. The loading histories in the two tests were different. In one test, the applied lateral loads were increased in a step-wise manner; in the other, story drifts of 5% in each direction were induced, generating a single large hysteretic loop. Comparisons between these two experiments are drawn and two analytic solutions are reported for the second experiment. Calculations based on the assumption of elasto-plastic behavior indicate poor agreement with the experiment; similar calculations based on a degrading moment-rotation assumption led to excellent results.

● **6.6-59** Brankov, G., Sachanski, S. and Paskaleva, I., **Response of some structures in nonelastic stage,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 58, 8. (For a full bibliographic citation see Abstract No. 1.2-8.)

The responses of a five-story package lift-slab building with stairwell towers and a six-story monolithic reinforced concrete frame building with masonry infill are investigated, taking into account inelastic deformations in the structural elements. The 1971 San Fernando earthquake S16°E component, multiplied by 0.3, 0.5 and 1.0, is used for this purpose.

Inelastic strength and deformation characteristics of the columns and shear diaphragms are determined by theoretical and experimental investigations. The equations of motion are solved using a step-by-step integration procedure with changing stiffness in each successive time interval. The influence of the inelastic deformations on the redistribution of stresses among the different vertical diaphragms, as well as their influence on the redistribution of stresses in each diaphragm, is investigated.

6.6-60 Mazalov, V. N., **Dynamic bending of rigid plastic circular plate with fixed contour** (Dinamicheskii izgib koltsevykh zhestko-plasticheskikh plastin s nepodvizhnymi krugovymi konturami, in Russian), *Dinamika sploshnoi sredy, 14,* 1973, 57-66.

Characteristic properties of the dynamic behavior of rigid plastic structures are considered. The problem mentioned in the title is discussed as a special case.

6.6-61 Kato, B. and Akiyama, H., **Energy input and damage in structures subjected to severe earthquakes** (in Japanese), *Transactions of the Architectural Institute of Japan, 235,* Sept. 1975, 9-18.

Housner assumed that the energy input contributing to structural damage can be expressed as half the product of the mass of the structure and the velocity response spectrum. As yet, however, this assumption has not been established.

A general law on vibrational systems is that the total energy input exerted by an earthquake is equal to the sum of the energy absorption due to plastic deformation of a structure, the energy absorption due to the damping and the elastic vibrational energy. Structural damage corresponds to the energy absorption due to plastic deformation,

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and the energy input causing damage may correspond to the sum of the energy absorption due to plastic deformation and the elastic vibrational energy. Each component in the above law was evaluated from many numerical analyses of inelastic vibrational systems, and it was found that Housner's assumption is basically valid.

6.6-62 Tosaka, N. and Tsuboi, Y., **The nonlinear theory of thin elastic shells under the Kirchhoff-Love hypotheses—Part I: Fundamental equations and their approximations** (in Japanese), *Transactions of the Architectural Institute of Japan, 235*, Sept. 1975, 27-38.

The object of this paper is to establish the fundamental equations and their approximation in nonlinear theory of thin elastic shells under the Kirchhoff-Love hypotheses as a basis for analysis of elastic stability and large deflection. The derived nonlinear equilibrium equations for general-shaped shells, allowing for the effect of deformation on equilibrium, are given in terms of the stresses and displacements. Substituting the constitutive equations into the above equilibrium equations, the authors' fundamental equations are obtained from the strain measures and related quantities for shells. Each term in these rigorous and complex equations is estimated by the introduction of the concept of estimation about the order of magnitude for the important parameters (i.e. the membrane strain, the bending strain and the wavelength in the shell region).

A discussion of consistent and systematic approximations, corresponding to the basic assumption of small strains, from the exact fundamental equations of nonlinear shell theory is given for the above estimation.

6.6-63 Tani, S. *et al.*, **Restoring force characteristics of reinforced concrete seismic elements—Part 3: Influences of restoring force characteristics on dynamic response of structure** (in Japanese), *Transactions of the Architectural Institute of Japan, 228*, Feb. 1975, 39-48.

The influences that various restoring force characteristic factors of reinforced concrete have on earthquake response, especially on the maximum displacement, are discussed, using the NCL model given in a previous report. Steady-state responses to sinusoidal excitation are first stated. Factors of restoring force characteristics examined in this paper are expressions for modelling the skeleton curve, maximum shear force level, the area and the shape of the normalized characteristic loop. Maximum shear force level and the area of the normalized characteristic loop are the most important factors influencing the maximum displacement response. At the same time, it is difficult to judge whether the response values are on the safety side or not if the model hysteretic curves do not resemble those of real structures.

6.6-64 Muto, K. *et al.*, **Earthquake response analysis of elevators in tall buildings** (in Japanese), *Transactions of the Architectural Institute of Japan, 228*, Feb. 1975, 31-37.

Recent earthquakes have caused extensive damage to nonstructural elements of buildings, such as elevators, electrical equipment, communication systems, etc. Elevators in particular were significantly damaged by the 1964 Alaska and the 1971 San Fernando earthquakes.

The typical pattern of damage is as follows: During the early stage of an earthquake, the counterweights bend or break their roller guides and deform their rails. Consequently, they are thrown out of their rails; and as the earthquake progresses, the derailed counterweights inflict additional damage on guide rails, brackets, spreader beams and cars.

In this paper, dynamic analysis methods, which compute the behavior of moving elevators during an earthquake, are described. High-speed sample elevators ($v=9$ m/sec) installed in one tall building of 55 stories are analyzed. The results show that the maximum acceleration induced in the elevator is 3~4 times the maximum ground acceleration when the elevator is in the lower stories of the building and that this amplification factor decreases as the elevator reaches the upper stories. The maximum acceleration is not highly affected by whether the elevator is in motion or stationary.

6.6-65 Kanazawa, K. and Kawamata, S., **Vibration analysis of a system having nonlinear damping** (in Japanese), *Transactions of the Architectural Institute of Japan, 231*, May 1975, 31-38.

Vibration of a one-degree-of-freedom system with damping of the velocity proportional to the n-th power, mainly the second, is investigated. A unified asymptotic method is applied to the free vibration, and an equivalent viscous damping method is applied to the steady forced vibration under harmonic excitation.

Results of the unified asymptotic method agree well with those of the numerical methods, which are the Runge-Kutta-Gill method and Newmark's B method. It is shown by the analysis that the amplitude is inversely proportional to time when velocity-squared damping exists in the system.

The results of the equivalent viscous damping method come close to agreeing with those of the numerical methods. The differences of the two are small when the frequency of the external force is the same as the natural frequency but relatively large when it is one-third of the natural frequency. The response of the system having the

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velocity-squared damping is influenced by the value of the external force.

The response of a system having one mass, two springs and velocity-squared damping is obtained by the equivalent viscous damping method, and the optimum damping coefficient is discussed. This system seems suitable for isolating vibration caused by earthquakes, machines and so forth.

6.6-66 Takanashi, K. *et al.*, **Non-linear earthquake response analysis of structures by a computer-actuator on-line system—Part 1: Detail of the system** (in Japanese), *Transactions of the Architectural Institute of Japan, 229,* Mar. 1975, 77-83.

The objective of this research project is to analyze the nonlinear earthquake response of structures without assuming the nonlinearity of the structure or structural members but by directly using the actual behavior of a structure or structural members obtained from an on-line dynamic failure test. An on-line system has been developed at the Inst. of Industrial Science, Univ. of Tokyo for this purpose. The system consists of a digital computer and hydraulic actuators, which are directly connected through an A/D converter and a D/A converter.

This paper is more concerned with the details of the procedure for using the on-line system for response analysis than with the results of the analysis. The nonlinear differential equation that expresses the nonlinear earthquake response of the structure was analyzed using a piecewise linear method. The structural stiffness required for the analysis at each step was input directly into the computer from the experiment, which was conducted parallel with the analysis. At each step, the hydraulic actuators were used to deform the specimens in accordance with analytical predictions. Then, the stiffness anticipated by the experiment was taken into account for the analysis at the next step. This procedure was repeated step by step until the response of the structure was terminated. The experiment was also controlled by the computer through the D/A converter and the A/D converter, corresponding to a cumulative displacement at each step of the analysis.

The first trial was carried out on steel frame buildings and on reinforced concrete buildings. The results will be reported in a later paper.

6.6-67 Omote, Y. and Takeda, T., **Non-linear earthquake response study on the reinforced concrete chimney—Part 2: Analytical study of some realistic chimneys** (in Japanese with English summary), *Transactions of the Architectural Institute of Japan, 227,* Jan. 1975, 25-37.

The authors have previously described an analytical method for nonlinear earthquake response of reinforced concrete chimneys and results of simulation analysis of models tested under strong earthquake-like base motions.

This report discusses the dynamic response characteristics of six kinds of full-scale reinforced concrete chimneys using two representative earthquake records, whose maximum acceleration intensities were modified to the levels between 100 gal and 600 gal. It is shown that the displacement response values of chimneys can be estimated simply by the nonlinear response spectrum of a one-mass system.

● 6.6-68 Bertero, V. V. and Popov, E. P., **Hysteretic behavior of ductile moment-resisting reinforced concrete frame components**, *EERC 75-16,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1975, 81. (NTIS Accession No. PB 246 388)

Results obtained from investigating the hysteretic behavior of flexural critical regions subjected to high and low shears, and of interior beam-column subassemblages of reinforced concrete ductile moment-resisting frames, are summarized and evaluated.

When the average shear stress at the critical region of a flexural member exceeds a value of $3.5\sqrt{f'_c}$ (psi), with a load reversal exceeding the flexural yielding value, a significant degradation in the energy absorption and energy dissipation capacities occurs. By using an inclined web reinforcement in combination with vertical ties, stable hysteretic behavior was achieved of inelastic rotations up to 0.035 rads. in one sense, and 0.067 rads. during a full load reversal.

The hysteretic behavior of interior beam-column subassemblages after a reversal of loads inducing a displacement ductility ratio of 2.5 shows (1) a significant P-δ effect and (2) a drastic drop in strength, and especially in stiffness. This drop is caused by the slippage of the main bars of the beams through the interior joint. To avoid these effects, it is recommended that the reinforcement of the beams be designed and detailed to induce plastic hinge formation away from the column faces. The aseismic design implications of the results obtained are assessed and recommendations for improving present seismic code provisions are offered.

● 6.6-69 Miller, R. K., **The steady-state response of multidegree-of-freedom systems with a spatially localized nonlinearity**, *EERL 75-03,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Oct. 1975, 193.

This report is concerned with the dynamic response of a general multidegree-of-freedom linear system with a one dimensional nonlinear constraint attached between two points. The nonlinear constraint is assumed to consist of

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rate-independent conservative and hysteretic nonlinearities and may contain a viscous dissipation element. The dynamic equations for general spatial and temporal load distributions are derived for both continuous and discrete systems. The method of equivalent linearization is used to develop equations which govern the approximate steady-state response to generally distributed loads with harmonic time dependence.

The qualitative response behavior of a class of undamped chainlike structures with a nonlinear terminal constraint is investigated. It is shown that the hardening or softening behavior of every resonance curve is similar and is determined by the properties of the constraint. Also examined are the number and location of resonance curves, the boundedness of the forced response, and loci of response extrema, and other characteristics of the response. Particular consideration is given to the dependence of the response characteristics on the properties of the linear system, the nonlinear constraint, and the load distribution.

Numerical examples of the approximate steady-state response of three structural systems are presented. These examples illustrate the application of the formulation and qualitative theory. It is shown that disconnected response curves and response curves which cross are obtained for base excitation of a uniform shear beam with a cubic spring foundation. Disconnected response curves are also obtained for the steady-state response to a concentrated load of a chainlike structure with a hardening hysteretic constraint. The accuracy of the approximate response curves is investigated.

● 6.6-70 Mahin, S. A. and Bertero, V. V., **An evaluation of some methods for predicting seismic behavior of reinforced concrete buildings**, *EERC 75-5*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1975, 360. (NTIS Accession No. PB 246 306)

This report investigates the seismic behavior of three reinforced concrete buildings that suffered significant structural damage during recent earthquakes. Two computer programs are developed for assessing the nonlinear dynamic response of reinforced concrete buildings subjected to strong earthquake ground motions. The ability of these nonlinear analytical techniques, as well as conventional linear elastic methods, to identify the principal parameters that controlled the seismic behavior of these prototype structures is evaluated.

One of the computer programs developed during this investigation quantitatively evaluates the nonlinear characteristics of critical regions in reinforced concrete flexural members and estimates their ability to sustain inelastic deformations. The effects of axial load, spalling, and shear forces on the flexural characteristics of these regions are considered in the computer program for the case of monotonic loading.

The other computer program developed permits analysis of the nonlinear dynamic response of buildings idealized as two-dimensional rectangular frames composed of discrete beam, column and diagonal bracing members. Simplified bilinear, hysteretic member mechanical behavioral models are developed based on sectional stiffness properties obtained for the critical regions subjected to monotonic loading. Many of the parameters frequently associated with realistic structural systems can be considered in the analysis, including: (1) distributed and concentrated gravity loads, (2) rigid beam-column joints, (3) unsymmetrically reinforced beams, (4) axial deformations and axial load-bending moment interaction in columns, (5) compression buckling in slender diagonal braces, and (6) geometric nonlinearities. Both horizontal and vertical ground motions (accelerograms) can be accounted for in the analysis. In some cases, it is possible to analytically consider the effects of member failures and stiffness degradation.

Although these nonlinear analysis methods correctly identify the parameters that controlled the seismic response of each of the prototype structures studied in this investigation, the response histories were found to be sensitive to the structural modeling and, especially, to the ground motion characteristics. As a consequence of the early brittle failures of the prototype structures, the elastic analytical methods also correctly predicted the failure mechanisms. Interpretation of the elastic results, however, requires considerable effort and judgment, and estimates of many response parameters (such as drifts, internal forces and ductility requirements) based on elastic results are inadequate. These findings emphasize the need for explicit consideration of the effects of inelastic seismic behavior. A number of recommendations for improving seismic resistant design procedures are presented.

6.6-71 Naka, T. *et al.*, **Strength and hysteretic characteristics of steel-reinforced column** (in Japanese), *Transactions of the Architectural Institute of Japan, 232*, June 1975, 89–99.

Tests were conducted on a steel-reinforced concrete beam-column. The steel section was a full-web type. The grade of steel used was SM 50, which is similar in quality to ST 52.

Equations are given for the following: (a) column yield shearing strength, which tends to increase with the axial load of the column; (b) column yield bending strength; and (c) column strength under cyclic loading when the deformation amplitude is approximately ± 0.01 radians. A superposed strength method for obtaining column maximum bending strength is illustrated. When the hysteretic loop becomes unstable under cyclic loading, the deforma-

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tion amplitude decreases with the increase of the axial load of the column.

6.7 Nondeterministic Dynamic Behavior of Nonlinear Structures

● 6.7-1 Vaicaitis, R., **Nonlinear panel response to nonstationary wind forces**, *Journal of the Engineering Mechanics Division, ASCE,* **101**, *EM4*, Proc. Paper 11486, Aug. 1975, 333–347.

The vibration of a flexible elastic panel to nonstationary wind surface pressures is investigated by a Monte Carlo technique. The nonlinear glass panel response is performed in time domain by simulating resulting generalized random forces on a digital computer. Equations of motion are solved in a Galerkin sense by developing a modal solution. Stress and deflection response calculations are performed for panels located on the windward, leeward and side faces of the building. Aeroelastic panel instability with respect to static divergence and dynamic flutter also is investigated.

● 6.7-2 Kaul, M. K. and Penzien, J., **Stochastic seismic analysis of yielding offshore towers**, *Journal of the Engineering Mechanics Division, ASCE,* **100**, *EM5*, Proc. Paper 10884, Oct. 1974, 1025–1038.

An analytical procedure to determine the stochastic response of inelastic offshore towers to a nonstationary ground motion in a semiclosed form is described. The method is approximate, but the solution is obtained without recourse to time-consuming Monte Carlo solution generation techniques. The offshore tower is modeled as a lumped-mass system and the resisting forces are obtained as a combination of linear and hysteretic forces. A filtered shot noise process is used to represent earthquake ground motion. Nonlinear hydrodynamic drag forces and the structure-resisting hysteretic forces are replaced by appropriate linear forms by using the equivalent linearization technique. The system response is then immediately obtained from the Kolmogorov-Fokker-Planck equation for the linearized structure system as the solutions of a nonlinear first-order matrix differential equation. To confirm the validity of the method, an example problem is solved using this method and the Monte Carlo solution technique.

● 6.7-3 Iyengar, R. N., **Random vibration of a second order non-linear elastic system**, *Journal of Sound and Vibration,* **40**, *2*, May 22, 1975, 155–165.

A method is presented for obtaining, approximately, the response covariance and probability distribution of a nonlinear oscillator under a Gaussian excitation. The method has similarities with the hierarchy closure and the equivalent linearization approaches, but is different. A Gaussianization technique is used to arrive at the output autocorrelation and the input-output-cross-correlation. This, along with an energy equivalence criterion, is used to estimate the response distribution function. The method is applicable in both the transient and steady state response analysis under either stationary or nonstationary excitations. Good comparison has been observed between the predicted and the exact steady state probability distribution of a Duffing oscillator under a white noise input.

● 6.7-4 Beshai, M. E. and Dokainish, M. A., **The transient response of a forced non-linear system**, *Journal of Sound and Vibration,* 41, *1*, July 8, 1975, 53–62.

The nonstationary response of a forced nonlinear system is studied by using a perturbation procedure. The approximate analytical results are verified by numerical simulation for specific cases.

● 6.7-5 Hasselman, T. K., Bronowicki, A. and Chrostowski, J., **Probabilistic response of offshore platforms to seismic excitation**, *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2353, May 1975, 165–178.

Analysis is based upon an interactive soil-structure system with base excitation applied at competent rock. Nonlinear soil characteristics and distributed soil-pile interaction are linearized about operating strain levels. Seismic excitation is defined in terms of an energy distribution over frequency and time. Probabilistic response is compared with conventional response spectra results. Dynamic tuning between a deep water platform and a soft soil may result in unusually high response when fundamental soil and structure periods coincide. Longer soil periods resulting from stronger excitation may attenuate structural response.

6.8 Soil-Structure Interaction

● 6.8-1 Parmelee, R. A. and Ludtke, C. A., **Seismic soil-structure interaction of buried pipelines**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 406–415.

The seismic soil-structure interaction of a buried pipeline is examined using a simplified model of the system. In the analysis, it is assumed that seismic waves approaching through a homogeneous elastic medium propagate toward the buried pipe from negative infinity. The horizontal forces imparted upon the structure by these waves are considered to be normal to, and uniformly distributed along, the longitudinal axis of the pipe. Also, all cross-sections of the pipe are considered to be in the same condition; thus, the entire structure moves as a single unit.

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This plane strain assumption simplifies the analysis, but it is not compatible with the actual physical system. More sophisticated models must be developed in order to accurately represent the complex interaction phenomena of actual physical systems.

● 6.8-2 Chakravorty, A. K. and Ghosh, A., **Finite difference solution for circular plates on elastic foundations,** *International Journal for Numerical Methods in Engineering,* 9, *1,* 1975, 73-84.

In the present work the authors develop a finite difference method of analysis for any circular plate with any kind of loading on semi-infinite elastic foundations. No assumption regarding the contact pressure distribution is made. The equations are developed in nondimensional form and also the results are obtained in nondimensional form. These results are compared with available experimental results and the agreement between them is found to be much better than that of the previous works. The same method with slight modification can be applied to Winkler-type foundations and problems of circular plates with varying thicknesses.

● 6.8-3 Thau, S. A., Umek, A. and Rostamian, R., **Seismic motion of buildings with buried foundations,** *Journal of the Engineering Mechanics Division, ASCE,* **100,** *EM5,* Proc. Paper 10870, Oct. 1974, 919-933.

Transient and steady-state responses of a one-story building model with an embedded foundation subjected to plane horizontally polarized shear waves are derived and analyzed. Soil-structure interaction effects are especially emphasized and a comparison of the rigorous results is made with the results for an analogous simplified model for which the interaction effects are neglected. It is shown that a conventional mass-dashpot-spring model fails to describe the actual complicated interaction effects associated with the scattering of waves around the foundation.

6.8-4 Dorman, I. Ya., **Calculation of stresses in railroad tunnels from seismic loadings** (Otsenka napryazhennogo sostoyaniya zheleznodorozhnogo tonnelya ot seismicheskikh nagruzok, in Russian), *Sbornik nauchnykh trudov VNII transportnogo stroitelstva, 67,* 1975, 47-56.

A deficiency of standard methods for calculating seismic stresses in railroad tunnel design is demonstrated by means of a computer analysis of stresses in various types of tunnel casing. Methods for calculating seismic forces acting on underground structures are suggested.

6.8-5 Fotieva, N. N. and Dorman, I. Ya., **Calculation of seismic stresses in circular tunnel casing** (Opredelenie napryazhennogo sostoyaniya obdelki tonnelya krugovogo ochertaniya ot seismicheskikh vozdeistvii, in Russian), *Sbornik nauchnykh trudov VNII transportnogo stroitelstva, 67,* 1975, 107-114.

An algorithm is presented for the calculation of stresses and strains in circular tunnel casing due to simultaneous action of seismic compression and shear waves arriving in an arbitrary direction.

● 6.8-6 Seed, H. B., Lysmer, J. and Hwang, R., **Soil-structure interaction analyses for seismic response,** *Journal of the Geotechnical Engineering Division, ASCE,* **101,** *GT5,* Proc. Paper 11318, May 1975, 439-457.

It is noted that significantly different results may be obtained by halfspace and finite element analyses of the same soil-structure system. However, it is also shown that wide variations in results may be obtained by either approach alone depending on the details of analytical techniques used and the method of evaluating appropriate soil properties. It is suggested that the major limitation of finite element analyses is the current inability to evaluate three-dimensional effects, while the major limitations of halfspace approaches are that material damping effects in the soil are not considered, that analyses are not available for multilayered soil deposits and that the effects of adjacent structures are not usually evaluated. It is concluded that, at the present time, finite element analyses provide the best prospect for evaluating the probable behavior of soil-structure interaction systems. However, halfspace analyses will often provide adequate evaluations for structures located near the ground surface.

● 6.8-7 Wong, H. L. and Trifunac, M. D., **Interaction of a shear wall with the soil for incident plane *SH* waves: Elliptical rigid foundation,** *Bulletin of the Seismological Society of America,* **64,** *6,* Dec. 1974, 1825-1842.

The closed-form solution of the dynamic interaction of an elastic shear wall and the elastic homogeneous halfspace, previously known only for the rigid foundation with circular cross section, has been generalized to apply for the foundation with elliptical cross section. It is shown that the interaction equation depends on the incidence angle of plane *SH* waves and that this dependence gradually disappears as the elliptical cross section approaches the circular one. The effectiveness with which the rigid foundation can scatter the incident energy has been found to increase with the depth of the foundation.

● 6.8-8 Kats, A. Z., **Calculation of seismic intensities from the depth of structural foundations** (Opredelenie seismicheskoi ballnosti s uchetom glubiny osnovaniya fundamenta sooruzheniya, in Russian), *Voprosy inzhenernoi seismologii, 17,* 1975, 34-38.

A technique is presented for calculating the effects of the foundation depth of a structure on the intensity of

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earthquake motion. The analysis is based on the relationship between the thickness of soil layers and their spectral characteristics. The results are of practical interest in the design of tall buildings in seismic regions.

● 6.8-9 Richart, Jr., F. E., **Some effects of dynamic soil properties on soil-structure interaction,** *Journal of the Geotechnical Engineering Division, ASCE,* **101**, *GT12*, Proc. Paper 11764, Dec. 1975, 1193–1240.

Soils exhibit nonlinear shearing stress-shearing strain behavior as the strain level increases from nearly elastic to plastic conditions. Experimental shearing stress-strain data were approximated by a Ramberg-Osgood mathematical curve that may be incorporated into analytical procedures. The method of characteristics is presented as one analytical method for studying dynamic behavior of soils, fluids, and structures including nonlinear soil behavior, inelastic slip, and transient pore pressures in one and two-dimensional systems. Several types of model studies involving soil-structure interaction are presented to illustrate the new method of holographic interferometry and to emphasize the importance of test and construction details on the effectiveness of dynamic soil-structure interaction. The importance of positive contact between the foundation block and soil along the vertical faces is noted.

● 6.8-10 Ovunc, B. A., **Analysis of buildings on elastic medium under dynamic or seismic loads,** *Finite Element Methods in Engineering,* 639–659. (For a full bibliographic citation see Abstract No. 1.2-1.)

A method is developed for the dynamic analysis of a building on an elastic medium, considering the real mass distribution over the constituent elements. It is assumed that the material is homogeneous and isotropic, that the displacements and strains are infinitesimal and that the Euler-Bernoulli hypothesis is valid. The constitutive elements of the system are considered as space elements, with each element point having six freedoms: three displacements and three rotations. The element stiffness matrices for three-dimensional space are derived so that the equations of motion are satisfied at every point of the element. Taken into account are the effects that damping and the elastic material have on vibration of the member.

● 6.8-11 Banerjee, A. and Jankov, Z. D., **Circular mats under arbitrary loading,** *Journal of the Structural Division, ASCE,* **101**, *ST10*, Proc. Paper 11637, Oct. 1975, 2133–2145.

The analysis of mats used in nuclear power plants may be difficult when a large number of features are taken into account. Circular mats and arbitrary loadings are only a few of these features considered in this paper. If the subgrade reaction can be represented as the function of subgrade displacement as given by Winkler's, Boussinesq's, or two elastic characteristic approaches, the general numerical method is then possible. Boussinesq's approach was treated in more detail when applied to a circular mat with arbitrary loadings. Full polar grid formation that must be used when liftoff occurs is compared to harmonic formulation. The possibility of taking into account the superstructure restraint is indicated.

6.8-12 Hadjian, A. H., Luco, J. E. and Tsai, N. C., **Soil-structure interaction: Continuum or finite element?,** *Nuclear Engineering and Design,* 31, 2, 1974, 151–167.

A survey of both the continuum and the finite element approaches to the soil-structure interaction problem is made. The limitations and advantages of both methods are evaluated with an emphasis on the present state of the art. Some recommendations are made regarding the circumstances under which either approach should more appropriately be used.

6.8-13 Tsai, N. C. *et al.*, **The use of frequency-independent soil-structure interaction parameters,** *Nuclear Engineering and Design,* 31, 2, 1974, 168–183.

The validity of approximating frequency-independent foundation impedance functions by constant parameters was evaluated for nuclear power plant structures. The soil-structure interaction system with the frequency-dependent impedances was analyzed using the Foss method to uncouple the equations of motion; this closely follows the method developed by Jennings and Bielak. The interaction system with the constant impedances was analyzed approximately by the normal mode method using equivalent modal damping values computed according to a procedure developed by Tsai. The above two methods were applied to simplified containment structural models founded on an idealized elastic halfspace, the shear wave velocities being taken to be 600, 1150, 2000 and 10,000 ft/sec. The results such as frequencies, damping, and in-structure response spectra were then compared. It was concluded that frequency-independent foundation impedances can be adequately used for plant sites having relatively deep and uniform overburdens.

6.8-14 Hadjian, A. H., Niehoff, D. and Guss, J., **Simplified soil-structure interaction analysis with strain dependent soil properties,** *Nuclear Engineering and Design,* **31**, 2, 1974, 218–233.

Recent work regarding the response of above-ground soil structures, such as dams, has indicated the need to use strain-dependent soil properties. Unlike other building materials, soil stiffness and damping properties are highly strain dependent. The application of these concepts to problems in soil-structure interaction also has been suggested. Without commenting on the appropriateness of this extension to soil-structure interaction problems, it is suggested that answers similar to those given by the strain-dependent solution of finite element models can be obtained more simply by the use of lumped-parameter impedance functions. To establish this equivalence, it is imperative that all other variables in the problem be made equal for both models; that is, the strain dependency problem must be isolated if the comparison of the two approaches is to be meaningful. The proposed method uses a damping value equal to the average strain-dependent soil profile damping. The strain-dependent soil profile damping values are obtained by the use of a much simpler model using one-dimensional wave propagation theory. From this same one-dimensional model, the strain-dependent soil stiffness corresponding to the average top layer of soil with and without an overburden to approximate the superstructure is used in the equivalent simplified model. Several case comparisons indicate the validity of the proposed method.

6.8-15 Luco, J. E., **Impedance functions for a rigid foundation on a layered medium,** *Nuclear Engineering and Design,* 31, 2, 1974, 204-217.

The problem of the harmonic forced vibrations of a massless rigid disc supported on an elastic layered medium is studied. The elastic medium consists of a layer of constant thickness placed on an elastic halfspace. The contact between the layer and the underlying halfspace is such that continuity of displacements and stresses at the interface is secured. Forced vertical, rocking and horizontal vibrations with harmonic time dependence are considered under the assumption of relaxed bonding between the rigid disc and the surface layer. The resulting mixed boundary value problems are reduced to sets of Fredholm integral equations that are solved numerically for a wide range of frequencies. The force-displacement relationships thus obtained present several differences with the corresponding results for a homogeneous halfspace. In general, the rocking impedances are the least affected by layering, while the vertical impedances are the most affected. The impedances for a layered medium show a stronger frequency dependence than the impedances for the halfspace. For intermediate and high contrast between the elastic properties of the layer and those of the halfspace, there is a considerable reduction of the radiation damping for low frequencies.

6.8-16 Luco, J. E. and Hadjian, A. H., **Two-dimensional approximations to the three dimensional soil-structure interaction problem,** *Nuclear Engineering and Design,* 31, 2, 1974, 195-203.

The feasibility of representing a three-dimensional soil-structure interaction problem by a plane strain model, and the errors involved in such representation, were studied. By comparing the rocking and translational force-displacement relationships for a rigid circular foundation placed on an elastic halfspace and the corresponding relationships for a strip footing placed on an elastic half-plane, it was found that it is not possible to obtain a two-dimensional representation that will approximate both the dynamic stiffness and radiation damping over a reasonable range of frequencies. Several two-dimensional models were considered and a measure of the errors involved is presented. In general, the two-dimensional models overestimate the radiation damping associated with the three-dimensional problem. To study the effects that the use of a two-dimensional plane strain model may introduce in the solution of the soil-structure interaction problem for typical nuclear power plants, a comparison was made between the system frequencies and modal dampings obtained for three- and two-dimensional models. The corresponding response at the top of the containment shell, top of the internal structure, and at the base slab for a particular earthquake also were compared. It was found that by properly selecting the two-dimensional model it was possible to obtain close approximations to the system frequencies. However, since the dampings associated with the low frequency modes are overestimated, the earthquake response of the structure, as obtained by the two-dimensional model, is underestimated to a significant degree.

6.8-17 Luco, J. E., Hadjian, A. H. and Bos, H. D., **The dynamic modeling of the half-plane by finite elements,** *Nuclear Engineering and Design,* 31, 2, 1974, 184-194.

A comparison was made between the vertical, rocking and horizontal impedance functions for a rigid strip foundation placed on homogeneous soil obtained by the finite element approach and the corresponding functions obtained for an elastic half-plane. An attempt was made to determine the overall size of the finite element model and the material damping necessary to approximate the two-dimensional half-plane results over the frequency range of interest. The results of this study indicate that even for large overall sizes of the model the impedances obtained by the finite element approach present important oscillations depending on the value of the frequency. Such oscillations may be reduced by further increasing the overall size of the model or by increasing the material damping; however, the last approach would lead to an overestimation of the radiation damping. The errors associated with the vertical, rocking and horizontal impedances are of different magnitudes, the largest corresponding to the vertical impedances. The size of the elements was chosen so that the impact on the results obtained would be minimal. It is expected that the use of larger-sized elements would further complicate the modeling problem.

● 6.8-18 Meek, J. W., **Effects of foundation tipping on dynamic response,** *Journal of the Structural Division, ASCE,* 101, ST7, Proc. Paper 11411, July 1975, 1297-1311.

When subjected to severe ground shaking, a slender building may begin to tip about the edge of its foundation. Methods have been presented that allow the influence of

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tipping to be considered in the dynamic analysis of single-mass models of structures. Solutions have been obtained for the response of tipping systems subjected to simple transient ground motion. Two main effects of tipping on dynamic response have been identified. First, in comparison to fixed-base behavior, tipping leads to a favorable reduction in the maximum transverse deformation suffered by a structure. By contrast, the second effect is potentially dangerous. After a period of tipping when the foundation slams into renewed contact with the ground, collision impulses are generated in the superstructure and the supporting soil. These short-duration, high-intensity normal forces could conceivably endanger the stability of the structure's compression members or lead to foundation failure.

● 6.8-19 Wong, H. L. and Trifunac, M. D., **Two-dimensional, antiplane, building-soil-building interaction for two or more buildings and for incident plane *SH* waves,** *Bulletin of the Seismological Society of America,* **65**, *6*, Dec. 1975, 1863–1885.

Two-dimensional *SH*-type vibration of several shear walls erected on an elastic, homogeneous halfspace is studied. The choice of the cylindrical coordinate system, suitable for analysis of rigid foundations with semicircular cross section, leads to the exact infinite series solution, which is ideal for the analysis of the physical nature of this problem and its dependence on several key parameters.

It is shown that the presence of neighboring buildings may change the nature of the single soil-structure interaction problem appreciably and that scattering, diffraction, and interference of waves from and around several foundations with the incident *SH* waves can lead to significant shielding, as well as to amplification of input motion for any of the buildings in a group. The effects of the relative size of two, three and several foundations and their separation distances are studied and presented in some detail.

● 6.8-20 Kuribayashi, E. and Iida, Y., **An application of finite element method to soil-foundation interaction analyses,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 151–158.

The results of field vibration tests and soil-foundation interaction analyses of the Kanmon Bridge are discussed. The three-span suspension bridge has a 712-m center span crossing over the Kanmon Strait between Shimonoseki on the island of Honshu and Moji on the island of Kyushu. The foundation on the Shimonoseki side is 40 m wide, 20 m long and 14 m deep and weighs approximately 25,000 t. The foundation on the Moji side is 40 m wide, 20 m long and 30 m deep and weighs approximately 50,000 t. Both foundations rest on layers of solid rock.

Sinusoidal vibratory horizontal forces, up to 35 t at 5.5 c/s and 40 t at 12 c/s, were applied to the foundation tops. Because of the appearance of several resonant-like peaks in the resonance curves, soil-structure interaction analyses were conducted. The elastic soil moduli were found to be considerably greater (about 5 times) than those used in the design. Therefore, displacements due to seismic excitations during future earthquakes may be smaller than those planned for in the design. For structures with large foundations, it is necessary to consider the effects of geological and topographical features and the effects of adjacent structures. The dynamic characteristics of the structures can be satisfactorily obtained by using a response analysis based on the finite element method.

● 6.8-21 Chandrasekaran, A. R., Petrovski, J. and Bickovski, V., **Effect of embedment and soil properties on the fundamental frequency of stiff multistorey buildings,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 159–162.

Field tests on stiff buildings, such as prefabricated box-like structures, have indicated that the natural frequencies of vibration are very much different from those computed by assuming the buildings to be fixed at the base. Soil-structure interaction effects are important for such buildings. The depth of embedment of the foundation of the building also would be an important parameter in such cases. This paper deals with the effect of these parameters on the fundamental frequency of vibration of multistoried buildings.

● 6.8-22 Christian, J. T. and Nivargikar, V. R., **Evaluation of structure response supported on deep soil deposits,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 163–170.

Various available models and techniques for analyzing earthquake-induced ground motions at the base of structures underlain by deep soil deposits are discussed. A typical case history of such an analysis is presented, using a simplified one-dimensional model with continuous shear beam analogy to represent soil deposit and wave equations.

In general, the customary procedure of adopting the maximum induced acceleration as a base input for evaluating the response of structures is observed to be overconservative. A reasonable procedure is to consider the effect that the fundamental frequency of a structure has on the response computed from the response spectrum over a range of frequencies. It is concluded that the amplification ratio, defined as motion at the base of the structure divided by the bedrock motion as a function of frequency, is a good measure for evaluating the response of soil-supported structures.

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● 6.8-23 Bielak, J., **Dynamic behaviour of structures with embedded foundations,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3,** *3,* Jan.-Mar. 1975, 259-274.

A study of the dynamics of building-soil interaction is presented that includes embedding of the foundation and material damping. By considering buildings on rigid footings embedded in linear elastic soil with hysteretic damping, it is shown that the earthquake response of the building-foundation model may be found from the response to modified excitation of equivalent one-degree-of-freedom linear, viscously damped oscillators resting on rigid ground. For a single-story building approximate formulas are developed for the modified natural frequency and damping ratio.

Results show that the natural frequency and damping in the system increase with embedding. Effective damping also increases with internal friction in the soil. Ignoring these two factors may underestimate considerably the effective natural frequency and damping in the system. In spite of additional sources of energy dissipation provided by the soil, damping in the equivalent oscillator may be greater or smaller than that corresponding to the superstructure alone, depending upon the system parameters.

For lightly damped superstructures, the peak amplitude of the steady-state overturning moment at the base of a building supported on flexible soil is significantly smaller than that corresponding to rigid ground. This result has practical implications for earthquake design.

● 6.8-24 Chilton, P. D. and Achenbach, J. D., **Forced transient motion of a rigid body bonded to a deformable continuum,** *Journal of Applied Mechanics,* **42,** Series E, 2, June 1975, 429-434.

The dynamic response of a rigid mass supported by a deformable continuum is investigated for the case when the mass is subjected to a load of arbitrary time dependence. The motion of the mass generates waves in the supporting continuum. The accompanying radiation of energy provides a damping mechanism for the motion of the mass. In this paper two-dimensional problems are investigated for which the wave motion in the supporting continuum is governed by a single wave equation. Two examples to which the results apply are (a) normal motions of a rigid line element supported by a stretched membrane, and (b) antiplane motions of a rigid strip bonded to an elastic halfspace. The traction between the rigid body and the supporting continuum is determined in subsequent intervals of time, and the velocity and displacement of the mass are computed. Numerical results are presented for the case when the applied load is a step function with time.

● 6.8-25 Crouse, C. B. and Jennings, P. C., **Soil-structure interaction during the San Fernando earthquake,** *Bulletin of the Seismological Society of America,* **65,** *1,* Feb. 1975, 13-36.

Accelerograms obtained at two sites during the San Fernando earthquake of 1971 were analyzed to investigate the role of soil-structure interaction, using techniques developed by Bielak and others. Analysis of the data from the site of the Hollywood Storage Building, for which data from the Arvin-Tehachapi earthquake of 1952 are also available, showed evidence of soil-structure interaction in the way the transfer functions between parking lot and basement motion decayed with increasing frequency in the two lateral directions. It is concluded also that interaction probably had a small effect on the response near the EW fundamental frequency during the San Fernando earthquake. Although theoretical and experimentally determined transfer functions are broadly similar, they do not agree in detail. The lack of good agreement for reasonable choices of the parameters of the theoretical model indicates a need for some modifications of the theory or its application, and a need for more measurements at the site.

A similar analysis showed no clear evidence of soil-structure interaction for the Millikan Library and Athanaeum buildings on the campus of the California Inst. of Technology. If soil-structure interaction caused the major differences measured in the base motions of these two buildings, it is of a more complex form than that considered by present theories.

● 6.8-26 Toki, K. and Takada, S., **Earthquake response analysis of underground tubular structure,** *Bulletin of the Disaster Prevention Research Institute,* **24,** 2, June 1974, 107-125.

The present paper deals with the vibrational characteristics of the longitudinal and transversal vibration of underground tubular structures subjected to earthquakes. The analytical model is composed of a cylindrical tubular structure the axis of which is parallel to the ground surface and the surrounding ground is treated as an infinite homogeneous halfspace. From the analyses on the structural response to sinusoidal excitation, it was found that the vibration of the structure due to the inertia force will hardly be induced in the ground and that the dynamic motion of the structure is strongly dominated by the ground motion. Moreover, analyses on the axial and bending strains revealed that the axial strain is proportional to the velocity amplitude of the surrounding ground, while the bending strain is proportional to the acceleration amplitude. The results suggest that the velocity amplitude in the ground is the most significant factor in the seismic-resistant design of underground pipe systems and the acceleration amplitude is of importance for structures with large diameters such as subway tunnels. Response analyses

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of strains to strong-motion accelerograms also have been performed by making use of the Fourier transform method. The analyses made clear that the effect of structural stiffness on the induced strain level is not so remarkable and the reduction of strain in structure from the strain in surrounding ground is of the order of 10 to 20%. Then, the strain in the ground is considered to be the upper bound of strain in structures.

● 6.8-27 Petrovski, J., **Evaluation of soil structure interaction parameters from dynamic response of embedded footings**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 43, 8. (For a full bibliographic citation see Abstract No. 1.2-8.)

The prediction of soil-structure interaction parameters, using the theory of surface footings, greatly overestimates the real response of structures or foundations. This is due to neglecting the facts that structures are partly embedded in the soil media and that a proper evaluation of soil properties under different levels of excitation, particularly in the inelastic range of behavior, must be made.

In order to develop a more suitable procedure for evaluation of soil-structure interaction parameters, an intensive research work, involving about 200 dynamic field tests on embedded and surface foundations, was carried out at IZIIS, Univ. of Skopje. Using the experimental results and modified theoretical solutions, a reverse procedure for evaluation of equivalent linear dynamic properties of the soil media was applied. Consequently, the stiffness and damping parameters of a discrete model of embedded footings were determined and the same procedure was applied in evaluation of soil-structure interaction parameters of a five-story building for the level of excitation obtained, on foundation level, during a forced-vibration test of a full-scale structure.

It was found that with the performance of dynamic field tests on embedded footings, simulating the foundation of the structure and using the described procedure, an accurate determination of equivalent linear dynamic properties of the soil media, as well as soil-structure interaction parameters, can be obtained.

● 6.8-28 Ionescu, C. *et al.*, **The seismic response of soil foundation structure systems**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 44, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The soil-structure interaction phenomenon is formulated in matrix form; the differential motion equation of the building is solved by a step-by-step technique, using a FORTRAN IV program. Results and conclusions obtained by solving some structures with 5 and 10 stories are presented.

● 6.8-29 Petrovski, J., **Influence of soil-structure interaction on the dynamic response of structures**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 45, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Existing methods for analysis of the dynamic response of structures, applying the assumption of a fixed structure in the soil media, consider soil as a rigid nondeformable media. This assumption is widely adopted since it simplifies mathematical solution of the problem, but it has little physical justification.

Using experimental results from dynamic tests of embedded foundations and a full-scale five-story building for the same soil conditions, the author determined the soil-structure interaction parameters of the building. By comparing the dynamic response of the fixed and flexible base models, an increase of base shear of an order of 20 and 50 per cent for close and distant earthquakes was obtained, respectively.

It is concluded that for the structure studied or for similar structures, such as large panel prefabricated buildings, masonry buildings and bridge piers, soil-structure interaction has a very important influence on the dynamic response and that it is desirable to take it into account in the analyses.

● 6.8-30 Kuribayashi, E. and Iida, Y., **An application of finite element method to soil-foundation interaction analyses**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 38, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper discusses the soil-foundation interaction of an actual structure. The Kanmon Bridge, completed in Nov. 1973, is a three-span suspension bridge with a 712 m center span crossing over the Kanmon Strait between Shimonoseki on the main island of Honshu and Moji on the island of Kyushu. During the construction period, dynamic field tests on both of the foundations of the two main towers, the so-called main piers, were carried out. In this paper the results of field vibration tests on the Moji pier and some soil-foundation interaction analyses are presented.

● 6.8-31 Aliev, G. *et al.*, **Influence of properties and stressed state of systems on structures' response**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 83, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The results of tests of free and forced oscillations of simplified models of structures—physical oscillators made of different materials, embedded into rocky, sandy and clayey foundations—are presented. The tests were con-

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ducted according to the centrifugal method with the use of the experimental device AZIS-2. Site tests of buildings and a test of the rigidity of the flat and spatial frames in different stressed deformed states also have been performed. The tests were directed at studying the influence of the pliability of the foundation and the stressed state on the response of systems to seismic forces.

● 6.8-32 Kobori, T. and Shinozaki, Y., **Torsional vibration of structure due to obliquely incident SH waves,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 22, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The problem considered is the vibration of a structure mounted upon a rigid circular footing on a soil medium which is subjected to plane harmonic SH-waves obliquely incident to the ground surface. The boundary conditions at the ground surface are treated as a mixed boundary value problem. Attention is focused on the effect of the incident angle of SH-waves on the dynamic characteristics of the torsional vibration as well as on the translational vibration of the single-story structure which is idealized to have no eccentric mass and rigidity distributions.

● 6.8-33 Sotirov, P., **Hysteretic damping of a soil-structure system for determination of modal damping,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 32, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

A soil-structure system with hysteretic damping of both soil and structure is investigated. Damping values of soil and structure are included in the complex stiffness matrix. Natural frequencies and modal dampings are determined by the real and imaginary parts of the complex eigenvalues. The obtained damping values can be used in modal response analyses.

● 6.8-34 Ionescu, C. D. and Barbat, H., **The soil-structure interaction and the soil amplification phenomenon,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 46, 3. (For a full bibliographic citation see Abstract No. 1.2-8.)

The problem of the formulation of the soil-structure interaction phenomenon is of great importance. Starting from Whitman's theoretical formulations, the authors present the results of experimental measurements on buildings and in foundation pits to point out this phenomenon.

6.8-35 Assaulenko, O. P., **Effects of wave processes in soils and the correlation between space vibration modes of buildings during earthquakes** (Uchet vliyaniya volnovykh protsessov v gruntakh i vzaimnoi korrelatsii prostranstvennykh form kolebanii zdanii pri seismicheskikh vozdeistviyakh, in Russian), *Stroitelstvo i Arkhitektura, 4,* 1974, 31-35.

The problem of the effects of wave processes in soils and the correlation between space vibration modes of buildings is considered. The example of a tall frame building is used to demonstrate the substantial effect the type of soil has on the magnitude and components of seismic loads.

● 6.8-36 Wong, H. L., **Dynamic soil-structure interaction,** *EERL 75-01,* Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, May 1975, 240.

The dynamic response of a structure placed on a deformable soil medium subjected to seismic excitation is studied. The basic phenomena of soil-structure interaction was investigated by several analytical models supplemented by experimental observations; a brief review of literature in this discipline is also included.

Among the physical phenomena investigated: the effects caused by local topography, the interaction with other structures, and the dissipation of dynamic energy through the soil medium were described by exact series solutions. Foundations of arbitrary shape, however, were modeled by using an approximate integral representation. This latter method utilizes the principle of superposition and provides flexibility in analyzing numerically the three-dimensional disc foundations placed on the soil surface. The results indicate that the detailed description for the shape of a rigid foundation placed on a deformable soil medium is not essential in the overall response of the superstructure, but the stress distribution under the disc foundation is quite sensitive to these changes in detail.

In this report, several methods for the calculation of foundation compliances for several types of foundation models were discussed, some of which have direct practical applications. The importance of the base input motion induced by incident seismic waves is also stressed, because the seismic input, along with the foundation compliances, is necessary for a complete analysis of this problem.

● 6.8-37 Ukaji, K., **Analysis of soil-foundation-structure interaction during earthquakes,** *18,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Mar. 1975, 195.

Procedures and computer programs are developed for determining the response of soil-foundation-structure interaction systems during earthquakes and to investigate the nature of soil and interaction effects.

Assuming the linear elastic stress-strain behavior of the soil, the author develops a two-dimensional analytical model of soil-foundation-structure interaction. The model consists of one-dimensional structural members, a two-dimensional rigid foundation block, and quadrilateral finite elements which idealize soil deposits. The accuracy of the model is evaluated regarding the influences of artificial side boundary and finite element size. Parameter studies are performed for soil effects and interaction effects, changing soil properties, soil depth, earthquake motions, structures and foundation embedment depth. A second analytical model is developed to incorporate the nonlinear stress-strain behavior (i.e., linear vs. elastic-plastic or equivalent linear vs. elastic-plastic).

The parametric studies show that the existence of the foundation block considerably affects the response of the structure resting on the foundation and that the soil deposits play a key role in determining the magnitude and frequency characteristic of the response of soil-foundation-structure systems. Realistic response predictions of structures during intensive bedrock shakings can be achieved only by nonlinear analysis procedures. The overall studies show that the suggested analytical procedures are a promising approach for predicting the responses of soil and soil-foundation-structure systems.

● 6.8-38 Lysmer, J. *et al.*, **Efficient finite element analysis of seismic structure-soil-structure interaction,** *EERC 75-34*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1975, 29. (NTIS Accession No. PB 253 570)

This paper reviews the current level of accomplishment which may be achieved using finite element techniques for the performance of complete interaction analyses, and describes an efficient procedure which meets all desirable requirements without incurring excessive costs for design and analysis.

6.9 Fluid-Structure Interaction

6.9-1 Konstantinov, I. A., **Seismic response of gravity dam interacting with water** (Raschet gravitatsionnykh plotin na seismicheskie vozdeistviya s uchetom ikh vzaimodeistviya s vodnoi sredoi, in Russian), *Izvestiya VNII gidrotekhniki, 105*, 1974, 162-173.

The problem of vibrations of a rigid dam on an elastic base interacting with water is considered. The solution is based on the expansion of displacements by the vibration modes of the dam in the water. Mode shapes and natural frequencies are calculated, and the formulas necessary for earthquake-resistant dam design are derived.

The equations and formulas derived use the matrix-sum of the dam and the adjacent mass of water in place of the mass matrix of the dam occurring in similar calculations for the case of a dam in the absence of water. Corresponding expressions are obtained for the matrix elements representing the adjacent masses of water. Analogous calculations are possible for other types of dam design.

● 6.9-2 Wu, C. I. *et al.*, **Response of ground supported liquid storage tanks to seismic excitation,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 456-461.

An analytical formulation and an accompanying computer program are presented for determination of the free vibration natural frequencies of an elastic circular cylindrical shell filled to an arbitrary depth with an incompressible, inviscid liquid. Numerical values obtained for various limiting, special cases of this general problem are found to be in excellent agreement with the results of previous investigations.

6.9-3 Wylie, E. B., **Seismic response of reservoir-dam systems,** *Journal of the Hydraulics Division, ASCE*, **101**, *HY3*, Proc. Paper 11184, Mar. 1975, 403-419.

A numerical method is presented to model the transient response of a reservoir when subjected to vertical or horizontal boundary displacements. The procedure assumes the reservoir may be represented by a latticework of line elements and that motion in the continuum may be modeled by solving the one-dimensional transient flow equations in the elements. Thus the two-dimensional behavior is computed by motions in a combination of one-dimensional elements interconnected at nodes. A calibration of the latticework is made to assure accurate predictions of transient response. Comparisons with exact solutions of the two-dimensional hydrodynamic problem are presented for a step function input and for actual earthquake excitations. The temporal variation of hydrodynamic forces is computed on a vertical-faced dam in both a confined reservoir and in a semi-infinite reservoir. The interaction between a flexible tapered concrete gravity dam and a confined reservoir is studied. A shear-beam one-dimensional model of the dam is analyzed when loaded with the simultaneous hydrodynamic response of the reservoir.

● 6.9-4 Prasad, R. and Iyengar, R. N., **Free vibrations of a reservoir-foundation system,** *Journal of Sound and Vibration*, 39, 2, Mar. 22, 1975, 217-227.

The natural frequencies of a reservoir-foundation system are calculated by treating the foundation as a system of linear springs with inertia. The reservoir is treated as consisting of compressible liquid, and the influence of waves at the free surface is included. It is shown that the natural frequencies decrease monotonically as the depth of foundation participating in the motion increases. The influence of waves at the reservoir surface is negligible for the cases normally occurring in practice. It is also shown that the wavelength of motion along the reservoir has no influence on the frequencies when the foundation depth is large compared to the reservoir depth.

● 6.9-5 Krajcinovic, D., **Dynamic plastic response of beams resting on fluid**, *International Journal of Solids and Structures*, 11, *11*, Nov. 1975, 1235-1243.

This paper considers the two-dimensional problem of a wide rigid ideally plastic simply-supported beam resting on a semi-infinite pool of potential fluid. It is demonstrated that the problem reduces to determination of the apparent (added, virtual) mass of fluid reflecting inertial characteristics of the fluid resisting deformation. Using the theory of dual integral equations, an especially simple closed-form solution for the apparent mass is derived enabling solution of this significant problem.

● 6.9-6 Ibrahim, R. A. and Barr, A. D. S., **Autoparametric resonance in a structure containing a liquid, Part I: Two mode interaction**, *Journal of Sound and Vibration*, 42, *2*, Sept. 22, 1975, 159-179.

An elastic structure carrying a rigid circular cylindrical tank containing a liquid with a free surface is considered. Autoparametric coupling between a single structural freedom and the first antisymmetric sloshing mode is investigated theoretically and experimentally. Under the condition of principal internal resonance (i.e., when the natural frequency of the structure equals twice the liquid sloshing frequency) the response of the system is obtained by an asymptotic approximation taken to the second order. Both theoretical and experimental results show that the coupling between liquid sloshing and vertical structure vibration is rather weak.

● 6.9-7 Chandrasekaran, A. R. and Gupta, S., **Experimental verification of added mass concept as used for finding frequency of reservoir-dam systems**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 103-110.

For determination of the period of reservoir-dam systems, several authors have assumed that an added mass of water, as used for hydrodynamic pressure computations, be attached to the dam. Since there is an inherent discrepancy in the assumptions involved, model studies have been made to check the assumption and determine the influence of water levels on the fundamental period of both sides of the dam. A cantilever steel plate was used to model the dam. The extent of added mass has been determined for various cases assuming a parabolic and elliptic distribution along the height. It is shown that the depth of water is an important parameter that influences the extent of added mass.

● 6.9-8 Rao, P. V., **Calculation of added mass of circular and rectangular piers oscillating in water**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 97-102.

To facilitate calculation of hydrodynamic forces on submerged piers and intake towers during earthquakes, simple equations are developed from potential-flow theories originally given by Jacobsen for circular piers and by Riabouchinsky for rectangular piers. The equations can be used for circular or rectangular bridge piers and intake towers. The added-mass approach is utilized in developing these equations. Experimental data of several other investigators are re-analyzed and expressed in added-mass terms. The data are compared with the potential-flow theories and the equations proposed in this paper. Variation of the added-mass coefficient with the slenderness and fineness ratios of a pier is shown in graphs. Examples of a circular intake shaft and a plate-type pier are given to illustrate the method of calculation.

● 6.9-9 Ibrahim, R. A. and Barr, A. D. S., **Autoparametric resonance in a structure containing a liquid, Part II: Three mode interaction**, *Journal of Sound and Vibration*, 42, *2*, Sept. 22, 1975, 181-200.

Autoparametric coupling of the first antisymmetric liquid sloshing mode with two orthogonal structure freedoms in a simple structure containing a liquid is investigated theoretically and experimentally. Asymptotic approximation up to the first order shows four possible conditions of internal resonance. The response of the system is obtained analytically and numerically in the neighborhood of the internal resonance conditions. Under the principal internal resonance (i.e., when one of the normal mode frequencies is twice one of the other mode frequencies) the system possesses a steady-state response. Under the summed or differenced internal resonance (i.e., when one of the normal mode frequencies equals the sum or difference of two other natural mode frequencies) the system does not achieve a constant amplitude steady-state response.

Experimental investigations confirm the possible existence of most of the internal resonance conditions considered in the analytical study; however, theoretical amplitude-frequency response curves are rather higher than the experimental results. Experimental observations showed that other kinds of instabilities occur when the liquid free surface exhibits rotational flow at a forcing frequency just above twice the liquid sloshing frequency.

● 6.9-10 Laura, P. A. A., Paloto, J. C. and Santos, R. D., **A note on the vibration and stability of a circular plate elastically restrained against rotation**, *Journal of Sound and Vibration*, 41, *2*, July 22, 1975, 177-180.

This paper deals with the determination of the fundamental frequency of vibration of a thin, elastic plate elastically restrained against rotation along the boundary

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and subjected to a hydrostatic state of in-plane stress. A simple approximate expression, which also allows calculation of the buckling pressure, is obtained. Where possible, the results are compared with values available in the literature, and very good agreement is shown to exist.

● 6.9-11 Berge, B. and Penzien, J., **Three-dimensional stochastic response of offshore towers to wave forces,** *Preprints, 1974 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2050, May 1974, 173–190.

A theory has been developed to calculate the dynamic response of offshore towers to random wave forces. Vibrations are considered simultaneously in the orthogonal horizontal directions and for rotations about a vertical axis. A lumped mass model of the structure is used in the dynamic analysis. The ocean waves are considered to be a zero mean, stationary and ergodic Gaussian random process specified by the directional wave spectrum. Linear wave theory and the Morison equation are used to obtain spectral density functions for the wave forces on the structure. Drag forces are linearized. The equations of motion are solved in the frequency domain using the normal mode superposition approach. Spectral densities are obtained for the responses in the various modes in normal coordinates, and mean products of the responses are obtained by numerical integration of the corresponding spectral density functions over the frequency range. These response quantities are then transformed into statistics of displacements, rotations, shear forces and bending and twisting moments.

● 6.9-12 Mansour, A. E. and Millman, D. N., **Dynamic random analysis of fixed offshore platforms,** *Preprints, 1974 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2049, May 1974, 157–172.

An outline of a method that can be used to examine the structural dynamics of fixed offshore platforms is presented. Both the dynamic and random nature of the environmental loads are preserved in the analysis. In particular, loadings resulting from the action of random waves are treated as dynamic excitations and investigated using a combination of spectral analysis and lumped mass modal technique. Other loadings resulting from gravity, wind and current forces also are considered.

● 6.9-13 Liaw, C.-Y. and Chopra, A. K., **Earthquake analysis of axisymmetric towers partially submerged in water,** *International Journal of Earthquake Engineering and Structural Dynamics,* 3, 3, Jan.–Mar. 1975, 233–248.

A method is presented for analysis of the response of axisymmetric towers partly submerged in water to earthquake ground motion. The tower is idealized as a finite element system. The hydrodynamic terms are determined by solving the Laplace equation, governing the dynamics of incompressible fluids, subject to appropriate boundary conditions. For cylindrical towers, these solutions are obtained as explicit mathematical solutions of the boundary value problems; whereas they are obtained by the finite element method in the case of towers with a noncylindrical outside surface. The response to earthquake ground motion is determined by step-by-step integration of the equations of motion. Analyses of two actual intake towers are presented to illustrate results obtained by this method. The small computation times required for these analyses demonstrate that the method is very efficient. The effectiveness of this formulation lies in avoiding the analysis of a large system by using a substructure approach and in exploiting the important feature that structural response to earthquake ground motion is essentially contained in the first few modes of vibration of the tower with no surrounding water.

● 6.9-14 Gray, R. M., Berge, B. and Koehler, A. M., **Dynamic analysis of the North Sea Forties Field platforms,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2250, May 1975, 77–85.

The offshore structures of the Forties Field were investigated to determine their static and dynamic response to wave action. The dynamic analysis took into account the nondeterministic nature of waves by representing the sea as a wave spectrum.

A comparison of the results of the dynamic response analysis and the static analysis demonstrate that for extreme weather conditions, the static design is adequate.

● 6.9-15 Aktaş, Z. and Uluç, F., **Dynamic behaviour of liquid filled circular cylindrical shells,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 71, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper a numerical method to determine the natural circular frequency of an empty or partially liquid-filled circular cylindrical shell is briefly outlined. For the application of this method, governing partial differential equations of the shell are first reduced into a system of first-order ordinary differential equations. Then, a numerical method is used to solve the resulting boundary value problem. Numerical results for natural circular frequencies of an empty and a liquid-filled circular cylindrical shell are given and compared with some available solutions.

● 6.9-16 Finn, W. D. L. and Varoglu, E., **A study of dynamic interaction in a plate-reservoir system,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 61, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

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A closed-form solution for the steady-state vibrations of a long vertical plate, retaining a compressible inviscid fluid in a long reservoir, is presented. The plate is fixed to the horizontal rigid base of the reservoir. The top of the plate is free. The forced motion is generated by horizontal harmonic motion of the rigid base of the reservoir.

6.9-17 Gordeeva, S. P. and Shulman, S. G., **On calculation of seismic loads on hydraulic structures from spectral curves** (K opredeleniyu seismicheskikh nagruzok na gidrosooruzheniya po spektralnym krivym, in Russian), *Izvestiya VNII gidrotekhniki, 105,* 1974, 152–155.

Seismic loads on hydraulic structures surrounded by water are calculated on the basis of linear-spectral earthquake resistance theory. The formulas obtained are similar to those relating to civil and industrial buildings. The formulas give approximate values of seismic loads on the hydraulic structures only under the assumption that mode shapes of free vibrations are the same whether water is present or not. An exact solution of the hydroelastic problem is given.

6.10 Vibration Measurements on Full Scale Structures

● 6.10-1 Serrano F., A., **Experimental determination of the periods of vibration of buildings in Guayaquil** (Determinacion experimental de periodos de vibracion de edificios de Guayaquil, in Spanish), *Cuadernos del IIEA*, **I**, *1*, Oct. 1974, 27–42.

The periods of vibrations of 26 buildings were obtained through measurement of ambient vibrations. The buildings are located in various areas of the city of Guayaquil. The vibrations were recorded by means of a high-amplification seismograph. On the basis of the measured periods, an experimental formula, a function of the geometric characteristics of the buildings, was established to obtain the fundamental periods of vibration of the buildings.

6.10-2 Khachiyan, E. E., Zakaryan, V. A. and Pogosyan, O. K., **Instrumental observations of vibrations in tall buildings** (Instrumentalnye nablyudeniya za kolebaniyami vysotnykh zdanii, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94,* 1974, 138–145.

Results of experimental studies of dynamic properties of tall buildings necessary for calculating their free vibration modes are presented. Small vibrations in numerous buildings were measured. Empirical formulas containing various factors (e.g., number and stiffness of floors, filling, etc.) were obtained. Powerful vibration generators were used to obtain loads comparable to earthquakes with intensity 7 to 8 and to study the effects of earthquake damage on dynamic properties.

● 6.10-3 Foutch, D. A. *et al.*, **Full scale, three-dimensional tests of structural deformations during forced excitation of a nine-story reinforced concrete building,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 206–215.

Full scale, forced vibration tests of the nine-story reinforced concrete Millikan Library building on the campus of the California Inst. of Technology in Pasadena, California, were conducted during 1974. An eccentric weight vibration generator installed on the roof of the building was used to shake the building at resonance. The three-dimensional motion at approximately 50 points on each of six levels including the basement and at 100 points on the ground surrounding the building was measured. These tests were performed for shaking in both the transverse and longitudinal directions of the building. The tests revealed a substantial amount of deformation of the floor slabs and interaction between horizontal and vertical load carrying members. The tests also indicated that the deformation of the soil had a significant influence on the response of the building in the stiffer N-S direction.

● 6.10-4 Rea, D., Liaw, C.-Y. and Chopra, A. K., **Mathematical models for the dynamic analysis of concrete gravity dams,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3**, *3*, Jan.-Mar. 1975, 249–258.

The results from field tests on Pine Flat Dam near Fresno, California, are described. The results are then used in the formulation of a three-dimensional mathematical model of the dam and a two-dimensional mathematical model of one of the taller monoliths. The significance of these mathematical models in relationship to the behavior of concrete gravity dams during earthquakes also is discussed.

● 6.10-5 Tezcan, S. S. *et al.*, **Forced vibration survey of Istanbul Bogazici suspension bridge,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 152, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

Various dynamic parameters, such as natural periods, mode shapes and critical viscous damping coefficients of the Istanbul-Bogaziçi Bridge, are determined by means of a series of ambient and forced vibration surveys. Vertical deflections at midspan under static loading are also measured during a static load test.

Results of static and dynamic load tests provide important information regarding the accuracy of analytical and

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experimental methods of an analysis, and these results are in good correlation with design assumptions.

6.10-6 Popov, V. V. *et al.*, **Forced vibrations of three-layered shells with light filling** (Vynuzhdennye kolebaniya trekhsloinykh obolochek s legkim zapolnitelem, in Russian), *Rasseyanie energii pri kolebaniyakh mekhanicheskikh sistem*, NAUKOVA DUMKA, Kiev, 1974, 68–76.

Forced vibrations of a three-layered, symmetric, circular, cylindrical shell with light, transversally isotropic filling are studied. Lateral deflections of the filling are not taken into account. Internal losses in the filling are calculated with the energy dissipation properties of the filling assumed amplitude-dependent. The differential equations obtained are solved by Bubnov's method using a double trigonometric series, leading to a system of ordinary differential equations for the mode shapes.

6.10-7 Oba, S. and Toriumi, I., **The change in dynamic characteristics of apartment houses during construction** (in Japanese), *Transactions of the Architectural Institute of Japan, 227*, Jan. 1975, 39–46.

This paper examines the change in the dynamic characteristics (natural frequency and equivalent damping constant) of 48 five-story reinforced concrete apartment houses. The microtremors of the buildings were measured during the different phases of construction with respect to changes corresponding to the size and shapes. The measured values were compared with theoretically computed ones for the rocking vibration of a rigid body on an elastic ground.

A summary of the results is as follows: (1) Dynamic characteristics of a structure become clear when the condition is fulfilled that the height/width is ≥ 1 and the number of stories is ≥ 3. When this is not the case, the vibration of the ground itself is transmitted directly to the structure due to the great degree of damping in the ground-structure system. (2) Natural frequency correlates with the size and shape of a structure. Measured values become lower when the height/width is increased. This tendency is in general accord with theory. (3) The equivalent damping constant, though showing variation, tends to decrease when the height/width is increased, or when the natural frequency of the structure is decreased. The measured values are, however, comparatively lower than the theoretical ones. (4) The influence of the ground upon the natural frequency of a structure is clearly shown: the values are approximately 10% higher on natural ground than on filled ground. However, influences on the equivalent damping constant are not clear.

● **6.10-8** Rea, D., Liaw, C.-Y. and Chopra, A. K., **Dynamic properties of San Bernardino intake tower,** *EERC 75-7*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1975, 62. (NTIS Accession No. AD/A008406)

Three series of forced vibration tests were conducted on the intake tower located in Silverwood Lake near San Bernardino, California. In the first test series the water level in the reservoir was just above the base of the tower so the effects of water on its behavior were negligible. In the second and third series the water submerged nearly two-thirds of the tower. In the second test series the inside of the tower was empty, whereas in the third series the tower was filled with water to the same level as the water in the reservoir.

During these tests seven modes of vibration were excited. Three of the modes were transverse modes of the bridge connecting the tower to land. Three more modes involved longitudinal movement of the bridge deck which can occur only at amplitudes of motion smaller than the clearances in the bridge supports. Thus, of the seven modes excited during the forced vibration tests, only one mode would be excited with significant amplitudes during strong earthquake ground motion. The natural frequency of this mode was 2.1, 2.0 and 1.9 Hz in the first, second and third test series respectively, and its damping factor lay in the range 1.0 - 1.2 per cent of critical damping for each series.

The changes in resonant frequencies between test series, together with the measured mode shapes and estimated mass distributions of the tower-bridge system were used to calculate the added mass effects of the water outside and inside the tower. However, the added mass effects could not be determined with sufficient precision by this method to check the accuracy of analytical methods of calculating added masses. However, the analytical method was found to predict accurately the dynamic water pressure distributions that were measured during the tests.

● **6.10-9** Kircher, C. A. and Shah, H. C., **Ambient vibration study of six similar high-rise apartment buildings,** *14*, The John A. Blume Earthquake Engineering Center, Stanford Univ., Jan. 1975, 90.

Two 12-story highrise apartment buildings and four 8-story highrise apartment buildings, located in Escondido Village on the Stanford Univ. campus, were chosen for this study because of their identical designs. Having two or more buildings of identical design provides the opportunity to compare both the structural similarity of the buildings and the ambient level forces exciting the structures, as well as the method of analysis itself.

Natural frequencies and modal damping values were determined when possible. A mathematical procedure for the systematic comparison of two power spectra was developed. The reliability of the method of analysis was examined by comparing the results of two power spectral

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density plots obtained for the same location and direction in the same building.

6.11 Experimental Facilities and Investigations

● 6.11-1 Ibáñez, P., Smith, C. B. and Vasudevan, R., **Dynamic testing and seismic response analysis of pole-mounted electrical equipment,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 435-445.

To aid in improving the reliability of pole-mounted electrical installations, a program of analysis and testing was performed for evaluation of the dynamic response of such installations. Mathematical models were used to evaluate the adequacy of existing installations to withstand anticipated dynamic loads and to suggest improvements in the design of future installations.

6.11-2 Ospanov, N. M. and Khachenkova, N. P., **Investigations of earthquake resistance of brick masonry** (Issledovanie seismostoikosti kirpichnykh kladok, in Russian), *Tekhnicheskie nauki, 17,* 1974, 197-203.

Results are presented of experimental investigations of the strength of brick masonry used in office and residential buildings in Alma-Ata. The earthquake resistance of the masonry was measured by testing full-scale structures. Various methods for increasing its strength are discussed.

6.11-3 Kaptsan, A. D. and Glukhov, Yu. G., **Methods for laboratory generation of seismic waves** (Sposob vozbuzhdeniya seismicheskikh voln na modelyakh, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 87,* 1973, 64-69.

In the study of limiting states of structures under seismic loads the capability to reproduce real ground motions is especially important. Existing experimental apparatus is able to generate harmonic or simple damped vibrations. Two methods for generating impulse action and influencing the length and mode of vibrations are presented.

● 6.11-4 Clough, R. W. and Tang, D., **Seismic response of a steel building frame,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 268-277.

The results are described of Phase II of a series of shaking table tests of a three-story steel building frame, wherein doubler plates were welded into the panel zones to strengthen them so that yielding would no longer occur there. The purpose of the study was to obtain detailed data on the seismic response of a structure in which the girders and columns yielded appreciably and to compare this observed behavior with the response predicted by computer analysis. Included are a brief description of the test structure, the instrumentation, and the test procedures. In addition, a selected group of test results is compared with analytical predictions, and the problem of developing suitable mathematical models is discussed.

● 6.11-5 Otani, S., **Earthquake tests of shear wall-frame structures,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 278-286.

The inelastic behavior of multistory reinforced concrete shear wall-frame structures was studied by subjecting scaled model structures to a series of intense base motions on an earthquake simulator platform. This paper describes the observed behavior during the experimental study and evaluates the test results on the basis of linear analysis methods.

● 6.11-6 Popov, E. P., Bertero, V. V. and Chandramouli, S., **Hysteretic behavior of steel columns,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 245-254.

The findings of an experimental study of the behavior of plastic hinges in columns under repeated and reversed flexural loads are reported. As a result of these experiments, it is determined that, contrary to the widely held opinion, axially loaded columns can successfully withstand loads causing inelastic cyclic flexural moments. The final section of the paper is a list of recommended guidelines to be used in applying the experimental results to the actual design of structures.

● 6.11-7 Williams, D. and Godden, W. G., **Seismic behavior of high curved overcrossings,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 186-195.

A model study is described in which small reinforced concrete model structures of long curved highway bridges are subjected to seismic excitations. The basic model is an assemblage of deck, column and expansion joint components, whose linear and nonlinear characteristics are known. Effects of restrainer ductility, relative movement at the expansion joints and column ductility are reproduced. Horizontal and vertical components of ground motion are applied by means of a 20 ft x 20 ft shaking table, and the overall response and failure mechanism is noted. Conclusions are drawn regarding certain critical design aspects of long curved bridges.

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● **6.11-8** Coull, A. and El Hag, A. A., **Effective coupling of shearwalls by floor slabs,** *Journal of the American Concrete Institute,* **72,** 8, Title No. 72-31, Aug. 1975, 429-431.

Results are presented from a series of tests on small scale models to determine the effective bending stiffness of floor slabs coupling shear walls. The experimental results indicate the relative influence of the dimensions and shape of the walls (plane walls, flanged walls, and box cores), wall spacing, and slab dimensions on the effective width and stiffness of the connecting slab.

6.11-9 Sweet, A. L., Schiff, A. J. and Kelley, J. W., **Identification of structural parameters using low-amplitude impulsive loading,** *The Journal of the Acoustical Society of America,* **57,** *5,* May 1975, 1128-1137.

A parameter-estimation procedure is developed using the average of the response of a structure to a sequence of impulsive force loadings. The finite Fourier sine and cosine transforms of the averaged response are computed. Using a mathematical model of a linear one-degree-of-freedom system, whose acceleration response has normal uncorrelated noise added to it, the joint probability density function of the Fourier coefficients is found. Applying the principle of maximum likelihood, estimates for the per cent of critical damping, the natural frequency, and the magnitude of the impulse are computed using Marquardt's method. Data were generated by digital simulation, analog simulation, and by exciting an experimental model. The resulting estimates and their confidence intervals are shown in tabular form. Error analysis due to random impulsive forces, finite pulse width of the force loading, and correlation of the noise are performed. The technique can be used in estimating the damping of systems in which the response to impulsive loading can be measured but is small relative to the ambient response.

6.11-10 Kunukkasseril, V. X. and Chandrasekharan, K., **Concentrated-impact loading of circular plates,** *Experimental Mechanics,* **15,** *11,* Nov. 1975, 424-428.

A solution to the impulsive motion of a clamped circular plate due to concentrated axisymmetric impact is obtained. Experiments were conducted on a clamped circular plate model under half-sine-pulse loads with several pulse durations. Experimental results are compared with the numerical results.

6.11-11 Kluge, R. W. and Sawyer, H. A., **Interacting pretensioned concrete form panels for bridge decks,** *Journal of the Prestressed Concrete Institute,* **20,** *3,* May-June 1975, 34-61.

The authors report on original research and conclusions based on all available research on the use of precast, pretensioned, stay-in-place form panels without mechanical connectors for concrete bridge decks. A total of 57 specimens in four series were tested to destruction. Repeated loads in the low-cycle fatigue range were applied to 19 specimens. For all specimens 3 in. form panels pretensioned along their length (usually 6 ft) with 7/16 in. 270 kip strands at 9 in. centers were subsequently overlaid with 4 in. of concrete.

For the 18 in. wide beam specimens of Series A, the shear and flexural strengths were practically unimpaired by compositeness. In Series B the punching shear strength near a plain panel joint averaged only slightly less than for unjointed specimens. Also, in Series C the notch formed by these joints was found to have no adverse effect on resistance to distribution moment of the overlay. However, in Series B and D it was found that for strand development, transverse steel must be included in the form panels. Low-cycle fatigue tests provided evidence that fatigue is not a special problem for any of the failure modes tested.

Among the concluding design and construction recommendations, the most critical relates to adequate strand development and prevention of foreign material on the panel-overlay interface.

● **6.11-12** Jirsa, J. O., Meinheit, D. F. and Woollen, J. W., **Factors influencing the shear strength of beam-column joints,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 297-305.

The purpose of this investigation was to examine experimentally the significance of several parameters, including the amount of longitudinal column reinforcement, column load, and depth of column, on the shear strength of beam-column joints. The results of eight tests are reported; the shear strength as predicted by the equation for the shear strength of concrete as found in ACI 318-71 is compared with the measured results.

6.11-13 Hashmi, S. J. and Al-Hassani, S. T. S., **Large deflexion response of square frames to distributed impulsive loads,** *International Journal of Mechanical Sciences,* **17,** *8,* Aug. 1975, 513-523.

A study of the elastic-plastic response of portal and free-free square frames subjected to distributed magnetomotive impulse is made. A finite difference method which reduces the structure to small masses connected with light links is used to solve the equations of motion of the deforming frames. The links are assumed to have the same strength properties as the material of the structure. Another analytical method also is used which assumes rigid-plastic properties and also allows for changes in geometry during the transient response of symmetrically loaded rectangular frames. The instantaneous profiles obtained

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from the high-speed photographs and the final deflections substantiate the predictions of both analytical methods.

6.11-14 Vinogradov, O. G. and Rabkin, M. A., **On the possibility of simulating dynamic behavior of structures using viscoelastic models** (O vozmozhnosti modelirovaniya dinamicheskikh yavlenii v konstruktsiyakh na modelyakh iz vyazkouprugikh materialov, in Russian), *Izvestiya VNII gidrotekhniki, 107,* 1975, 78-83.

Simulation of dynamic processes in linear viscoelastic media is considered. The possibility of such simulation is established when the experimental parameters (e.g., the temperature of the model) depend nonlinearly on the parameters of the full-scale structure. Simulation of polyharmonic and nonperiodic processes is possible only in frequency. The experimental test results are applicable to the full-scale structure when the material of the latter differs from the viscoelastic model.

6.11-15 Pakulin, V. A., **Choice of parameters for instrumental recording of dynamic processes** (Vybor parametrov registriruyushchei apparatury dlya zapisi dinamicheskikh protsessov, in Russian), *Trudy NII osnovanii i podzemnykh sooruzhenii, 65,* 1975, 78-83.

Parameters of instrumentation for dynamic testing are discussed. Phase and frequency responses of galvanometers are considered and formulas for calculating instrumental error are presented. Practical examples are given.

6.11-16 Koyanagi, R. S., **Development of a low-frequency-vibration calibration system,** *Experimental Mechanics,* **15**, *11,* Nov. 1975, 443-448.

The development of the low-frequency vibration apparatus described in this report was done in response to a need to establish and verify vibration-pickup performance at infrasonic frequencies. The exciter design is an extension of the Dimoff type exciters and, in fact, many of its components are identical.

The motion of such an exciter must have very low distortion and minimal components of motion in all directions other than axial. In addition, the attainable amplitude must be large enough to produce a transducer signal that can be accurately measured. The attainable amplitude and accuracy of transducer calibration on this exciter are limited by transducer size, weight, geometry and vibration sensitivity. Examples of the types of accelerometers which can be calibrated on this exciter are servo or force balance, piezoelectric, piezoresistive and strain gage.

6.11-17 Chanukvadze, G., **Static testing of floor slab models in horizontal plane** (Staticheskie ispytaniya modelei mezhduetazhnykh perekrytii v gorizontalnoi ploskosti, in Russian), *Sbornik nauchnykh trudov zonalnogo nauchno-issledovatelskogo instituta tipovogo i eksperimentalnogo proektirovaniya zhilishchnykh i obshestvennykh zdanii, 7, 1,* 1973, 14-22.

The main theoretical and technical difficulties in the construction of tall frame-panel buildings are discussed. The structural elements contributing to the earthquake resistance of the building are isolated. Results of large-scale model testing of the stiffness of precast floor slabs are presented. The testing techniques are described and a partial analysis of the experimental results is given.

6.11-18 Edisherashvili, N. and Bagmanjan, A., **On model testing of dynamic response of tall steel frame buildings** (O metodike modelnykh ispitanii mnogoetazhnykh stalnykh karkasnykh zdanii na dinamicheskie vozdeistviya, in Russian), *Sbornik nauchnykh trudov zonalnogo nauchno-issledovatelskogo instituta tipovogo i eksperimentalnogo proektirovaniya zhilishchnykh i obshestvennykh zdanii, 7, 1,* 1973, 40-49.

Results of testing large-scale models of steel-frame structures are presented and the testing methods are described. Special attention is paid to measuring damping decrements.

● 6.11-19 Jubb, J. E. M., Phillips, I. G. and Becker, H., **Interrelation of structural stability, stiffness, residual stress and natural frequency,** *Journal of Sound and Vibration,* 39, *1,* Mar. 8, 1975, 121-134.

Results were collected on studies relating the stability load of a structure to stiffness and natural frequency. Additional experimentation was done to include effects of residual stresses and the major portion of this paper is devoted to a discussion of these studies. Finally, further examinations were made of recent theories to relate stability load, stiffness, frequency and residual stress.

The results are reported here in order to reveal the range of relationships that can be found among these four structural features, and to demonstrate a reasonably sound basis for nondestructive testing procedures to determine residual stresses and structural stability. Hopefully, it also will stimulate further research in this hitherto neglected area.

● 6.11-20 Zaslavskii, Yu. L., **On a possible automated drive mechanism for shaking tables** (Ob odnoi vozmozhnosti avtomatizatsii elektroprivoda seismoplatformy, in Russian), *Seismostoikost plotin, 3,* 1975, 165-171.

An automated drive mechanism with a programmed unit was designed for the shaking table at the Inst. of Earthquake Engineering and Seismology of the Academy of Sciences of the Tadzhik SSR in order to increase the precision and exact repetition of shaking table experiments

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in investigations of earthquake resistance of dams. The requirements for such mechanisms are considered, and problems involved in the design are discussed.

● **6.11-21** Zaslavskii, Yu. L. *et al.*, **Methodological problems of calibrating constant galvanometers** (Metodicheskie voprosy opredeleniya postoyannykh galvanometrov, in Russian), *Seismostoikost plotin, 3,* 1975, 48–55.

Traditional methods for evaluating the response characteristics of galvanometers (e.g., natural frequencies, electromagnetic damping coefficients, sensitivity and internal resistance) involve a great deal of time. The resonance method presented in this paper permits quick testing of galvanometers without multiple use of oscillographs and processing of oscillograms.

● **6.11-22** Maksimov, L. S. and Sheinin, I. S., **Vibration measurements in structures. A reference manual** (Izmerenie vibratsii sooruzhenii. Spravochnoe posobie, in Russian), STROIIZDAT Publishers, Leningrad, 1974, 255.

Data about methods and instruments for measurement, recording and analysis of vibration parameters are presented. Among the parameters considered are displacements, velocities and accelerations as well as dynamic strains and pressure fluctuations on the surface of the structure. Technical data about the most widely used mass-produced instruments are given. Practical recommendations for full-scale experiments and the organization of vibration measurements are set forth. The volume is intended for engineers engaged in investigations, design, construction, testing and maintenance of buildings.

The following chapters are contained in the book: Introduction; (1) Mechanical and optical instruments. Vibration measurement methods; (2) Primary vibration converters; (3) Recording devices; (4) Measurements of kinematic vibration parameters; (5) Measurement of dynamic strain; (6) Measurement of variable pressure; (7) Practical recommendations for structural vibration measurements; (8) Testing of structures by means of special dynamic loads; (9) Analysis of measurement records.

● **6.11-23** Okamoto, S. *et al.*, **A study on the dynamic stability of rock-fill dams during earthquakes based on vibration failure tests of models,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 77–86.

In order to determine the dynamic stability of rockfill dams, shaking table tests were conducted on large-scale two-dimensional models. The models were subjected to sinusoidal motions in one horizontal direction and were tested to failure, with the reservoir both empty and full. In addition, several small dam models were subjected to impact loads. Only an outline is given of the results since some of them have been published previously.

● **6.11-24** Baxter, G. K. and Evan-Iwanowski, R. M., **Response of a column in random vibration tests,** *Journal of the Structural Division, ASCE,* **101,** *ST9,* Proc. Paper 11568, Sept. 1975, 1749–1761.

Laboratory experiments were conducted to observe and measure the response amplitude and frequency of a simply supported column. The column was excited by axial forces generated from sinusoidal and random (bandwidths of 3, 10, 30, and 100 Hz) signals. The column will vibrate near its natural frequency if the excitation contains a sufficiently high level power spectral density within the parametric resonance zone of the column. The variance of the response amplitude decreases with increasing bandwidth of excitation. A zero amplitude of response is found during a considerable portion of the excitation time; this indicates there is a discrete component in the probability distribution at zero amplitude.

● **6.11-25** Wight, J. K. and Sozen, M. A., **Strength decay of RC columns under shear reversals,** *Journal of the Structural Division, ASCE,* **101,** *ST5,* Proc. Paper 11311, May 1975, 1053–1065.

The decay in shear strength of tied reinforced concrete columns during earthquake loading was investigated by subjecting 12 column specimens to several reversals of loading to deflections larger than the yield deflection. The principal variables of the test program were the axial load, the transverse reinforcement ratio, and the total deflection per cycle. The test specimens were able to develop the expected yield moment in the first quarter cycle and maintain that load for some inelastic deflection. However, the repetition of these deflections resulted in a decay in the strength of the member. Experimental data are used to examine the mechanism of strength decay, which is related to crushing and spalling of the shell concrete, yielding of the transverse reinforcement, and abrasive rubbing of concrete along inclined cracks. The results of this investigation indicate that the transverse reinforcement must be proportioned to carry the total shear required to develop the ultimate moment capacity of the column.

● **6.11-26** Singh, S. *et al.*, **Seismic modelling for engineering and exploration of seismology problems,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 409–414.

The seismic modelling facilities, being constructed at the Univ. of Roorkee to study engineering and exploratory seismology problems, are described. Included are discussions of the possible types of energy sources that could be used for exciting the model, the choice of design of the pulse generator and data used in the selection of suitable material for transducer backing and coupling.

● 6.11-27 Morino, S., Nakamura, T. and Wakabayashi, M., **An experimental study on the behavior of steel reinforced concrete cruciform frames,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 307-314.

An experimental study was conducted to determine the behavior of steel reinforced concrete beam-and-column assemblages, subjected to constant vertical and alternately repeated horizontal loads. The effects of the depth of the wide-flange steel section, the flexural strength ratio and the vertical load on the behavior of the specimens are investigated. Discussed are the maximum load-carrying capacities and the hysteretic behavior of flexure-failing specimens in the column and of shear-failing specimens in the connection panel. Bond failure is discussed in connection with the test results of specimens with ordinary reinforced concrete columns.

● 6.11-28 Kirillov, A. P., Ambriashvili, Ju. K. and Kozlov, A. V., **Full-scale and model studies of nuclear power stations for earthquake resistance,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 2, Nov. 1974, 30-37.

Existing nuclear power plants, as well as models of various sizes, were subjected to explosions and impulse loads. The purpose was to develop a model test procedure for evaluation of the possible range of dynamic stresses in nuclear power plant structures and pipelines. The results of the full-scale investigations show good agreement with the results of the model tests. The feasibility of model simulation is confirmed.

● 6.11-29 Popov, E. P. and Bertero, V. V., **Repaired r/c members under cyclic loading,** *International Journal of Earthquake Engineering and Structural Dynamics,* 4, 2, Oct.-Dec. 1975, 129-144.

As a part of a general program at the Univ. of California, Berkeley, in the study of the seismic behavior of reinforced concrete members, several severely cracked test specimens were repaired. The repair was made using either epoxy resin or concrete. In this paper a comparison of the performance of the original specimens with their performance after the repair is given. The repaired specimens were found to behave in a very satisfactory manner except where the injected epoxy had to restore a large region of destroyed bond between the concrete and the reinforcing steel. This condition was found to be particularly prevalent at the interior beam-column joints of moment-resisting frames. In such joints the bottom reinforcing steel of a beam tends to slip through a column due to the gradual bond degradation under cyclic loading. This is mainly caused by the formation of plastic hinges at the column faces. In order to avoid this condition, special details of reinforcement are suggested for controlling the location of plastic hinge formation.

● 6.11-30 Mihai, C. *et al.*, **Behaviour of some members and joints made up of resistive lightweight concrete compared to heavy ones, under static and dynamic loadings,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 111, 12. (For a full bibliographic citation see Abstract No. 1.2-8.)

With a view to using lightweight concrete composed of granulite for member or structural resistance to earthquakes, the results of research carried out on beams, columns and joints subjected to static and dynamic loads are presented and compared with the results obtained by testing similar members constructed of normal heavy reinforced concrete. On the basis of the results obtained to date, this paper includes assessments regarding the possibility of using the lightweight granulite concrete in seismic zones.

● 6.11-31 Oganessian, N. L. *et al.*, **Model studies of earthquake resistance of masonry buildings,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 110, 4. (For a full bibliographic citation see Abstract No. 1.2-8.)

The paper sets forth the results of an investigation of the efficiency of applying seismoisolating cushions in buildings for the purpose of mitigating seismic effects. The methods and results of static and dynamic experimental model tests of cushions and buildings on cushions are dealt with in addition to technical and economic considerations based on the application of cushions in masonry wall buildings.

The paper also presents the results of seismo-explosive action on the model of a large-block building.

● 6.11-32 Tanaka, Y. *et al.*, **Earthquake-resistant properties of reinforced concrete columns,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 91, 26. (For a full bibliographic citation see Abstract No. 1.2-8.)

During the 1968 Tokachi-oki earthquake in Japan, many reinforced concrete buildings collapsed as a result of column failures. Since then, the attention of researchers has focused on the behavior of reinforced concrete columns under seismic forces.

Two types of experimental tests were conducted on reinforced mortar and concrete column models to determine their ultimate strength during earthquakes. The results of these tests are discussed.

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● **6.11-33** Anicic, D. and Zamolo, M., **Stiffness deterioration of cyclic loaded reinforced concrete structural elements**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 113, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The results of laboratory testing of the behavior of reinforced concrete structural elements used for the connection of RC bearing shear walls in high-rise buildings are presented. The elements were subjected to quasistatic loading, as a simulation of strong seismic forces. The testing was performed on six large models (scale 1:2). The results offer insights into the shape of characteristic hysteresis loops and into the stress distribution in the main reinforcement and the stirrups.

● **6.11-34** Czarnecki, R. M., Freeman, S. A. and Scholl, R. E., **Destructive test of a 4-story concrete structure**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 108, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Results of a high-amplitude destructive-level vibration test of a four-story reinforced concrete structure indicate that the structure experienced a period of linear response followed by a period of inelastic response. This resulted in substantial structural damage and a permanent change in the damping and stiffness characteristics of the structure. After major damage, the response of the structure was similar to that of a linear system with a reduced stiffness.

● **6.11-35** Malyshev, L. K. and Monakhenko, D. V., **Physical model test problems of structural seismic stability**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 105, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Theoretical and experimental methods for investigation of structural seismic stability by physical model tests are presented. The structure and its physical model are idealized. Methods for comparing various model tests and computations are worked out.

A complex approach, using photoelasticity and the Moire method for investigation of seismic stability problems (wave dynamics, in particular) by physical models, is developed. Experimental procedures and techniques are described.

● **6.11-36** Atalay, B. and Penzien, J., **Inelastic cyclic behavior of reinforced concrete columns**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 100, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Twelve reinforced concrete members, each simulating a column, were tested to determine the modes of failure, to study the stiffness, strength, ductility and energy absorption degradation characteristics and to establish appropriate mathematical representations of inelastic cyclic behavior. The test variable parameters were (1) magnitude of applied axial load, (2) lateral reinforcement percentage, and (3) history of applied lateral displacements. Test results show that degrading mechanisms enhance and failure modes change with increasing applied axial load or with decreasing lateral reinforcement percentage, and in addition, member force-deflection characteristics can be calculated from internal deformations in the inelastic region.

● **6.11-37** Lee, D. L. N., Wight, J. K. and Hanson, R. D., **Repaired beam-column subassemblages subjected to earthquake type loads**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 95, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

An investigation of the repair and retests of reinforced concrete exterior beam-column subassemblages is presented. The specimens were designed using the current code for both seismic and nonseismic areas to represent many existing structures. During the original testing, the specimens were subjected to either moderate or severe earthquake loading to obtain different degrees of damage. Epoxy injection and various removal and replacement techniques were used to repair the specimens. Details of the repair procedure are given. A comparison of the peak-to-peak load and the energy dissipated between the original and repaired specimens is made. At equal displacements, the peak-to-peak loads for the repaired specimens are consistently higher than the original specimens and the energy dissipated is almost equal for both. It was concluded that epoxy injection and removal and replacement methods of repair can restore structural integrity.

● **6.11-38** Corley, W. G., **Laboratory tests of shear walls for multi-story buildings**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 92, 12. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper describes a shear wall test program, carried out at the Portland Cement Assn. Tests were on walls with proportions representing those of medium-rise and high-rise buildings. In discussing the test results, effects of reversed loads simulating earthquake effects are discussed and calculated strengths are compared with those measured. Moreover, factors that influence ductility are given. Finally, the meaning of shear strength provisions in current North American building codes is presented, and a comparison of these provisions with available test data is made.

6.11-39 Abdurashidov, K. S. and Ruzmetov, A. S., **Restoration methods for buildings with stone walls following strong earthquakes** (Metody vosstanovleniya zdanii s ka-

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mennymi stenami posle silnykh zemletryasenii, in Russian), *Stroitelstvo i Arkhitektura Uzbekistana, 1,* 1974, 1–4.

Eighteen stone wall fragments on a rigid footing were tested under horizontal in-plane loads. After crack formation the damaged fragments were reinforced with metal nets and gunite work and then were tested again under the same conditions. The reinforcing procedures, similar to the ones used in the reconstruction of stone walls damaged in the Tashkent earthquake of Apr. 26, 1966, are described. Numerical data on stiffness and strength increases after reinforcement are included.

6.11-40 Belogorodskii, B. A., **Application of holographic interferometry for calculating seismic pressure of water on structures** (Primenenie metoda golograficheskoi interferometrii dlya opredeleniya seismicheskogo davleniya vody na soorvzheniya, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki, 87,* 1973, 75–77.

Holographic interferometry is used to visually represent hydrodynamic pressure fields near a model. The possibility is pointed out that the calculation of the fields represented can be accomplished by use of the phase modulation of light by the hydrodynamic fields.

6.11-41 Chakhara, G. A., **A technique for obtaining force-displacement diagrams for a reinforced concrete space frame with rigid cross bars subjected to static and dynamic horizontal loads** (Metodika polucheniya diagramm "sila-peremeshchenie" dlya zhelezobetonnoi prostranstvennoi ramy s zhestkim rigelem pri staticheskom i dinamicheskom gorizontalnom nagruzhenii, in Russian), *Seismostoikost sooruzhenii, 3,* 1974, 150–159.

Calculation of the logarithmic decrement of free vibrations is indispensable when using the spectral method to construct force-displacement diagrams reflecting plastic deformations in reinforced concrete structures. Investigations of the experimental modeling of staggered static and dynamic loads are carried out. Static tests were performed without vertical loads and with vertical loads of 10 t, 20 t and 30 t. Models were tested separately for bending or shear stresses. Vibration generators were used to apply dynamic loads. The principal conclusion concerns the close relationship between force-displacement diagrams obtained with various loading patterns, which leads to the recommendation that testing be restricted to unilateral static loads without additional loads.

6.11-42 Demchenko, V. Ya. and Panteleev, A. A., **Application of holographic interferometry to the study of vibration modes of hydraulic structures on small-scale models** (O primenenii gologroficheskoi interferometrii k issledovaniyam form sobstvennykh kolebanii gidrotekhnicheskikh sooruzhenii na malomasshtabnykh modelyakh, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki, 87,* 1973, 74–75.

The principles used in investigations of vibrations by means of holographic interferometry are presented. The technique is then applied to the study of the free vibration modes and frequencies of small-scale models of hydraulic structures.

6.11-43 Suzuki, T. *et al.*, **Experimental study on the elasto-plastic behavior of tensile braced frames** (in Japanese), *Transactions of the Architectural Institute of Japan, 228,* Feb. 1975, 57–64.

To obtain the restoring force characteristics of low steel structures, an experimental study was made of the elasto-plastic behavior of a tensile-braced rigid frame.

Alternating horizontal force was applied at the point of the second floor under a constant vertical load, paying attention to the behavior of two columns subjected to varying axial forces. Test specimens consisted of one-story, one-bay rigid frames with wide flange sections and braces of round steel bars.

The relation between shear force and displacement in each column was investigated by numerical analysis. According to these results, the elasto-plastic behavior of the two columns is obviously different; one is subjected to additional tensile force and the other to additional compressive force.

From these results, it is found that the restoring force characteristics of braced frames are stable but that the hysteresis loops in each column become unstable because of the additional compressive force.

6.11-44 Fukuchi, Y. and Ogura, M., **Experimental studies on local bucklings and hysteretic characteristics of H-shape beams** (in Japanese), *Transactions of the Architectural Institute of Japan, 228,* Feb. 1975, 65–71.

Flange local buckling is one of the important factors in deciding the critical strength and deformation capacity of H-shaped beams. The b/t ratios of flanges are proposed with regard to plastic design methods. But, they are generally proposed as the result of monotonic loading tests. Accordingly, investigation under cyclic loading is necessary.

This report describes an experimental investigation of the strength and the deformation capacity of H-shaped beams under cyclic loads for flange local buckling. The specimens are H-shaped beams with four ratios, that is b/t = 15, 12, 10 and 8. Cyclic loads with the following five ratios are used: monotonic loading; 1:0.6 cyclic loading; 1:0 cyclic loading; 1:1 cyclic loading (load control) and 1:1

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cyclic loading (deflection control). The relationships between load and deflection are shown.

From the experimental investigation in this report, the following conclusions are drawn: (1) For the AA series (b/t = 15), the deformation capacity in the plastic region is little or none. (2) For the A, B and C series (b/t = 12, 10 and 8, respectively), the smaller b/t is, the larger is the difference of rotation capacity by the kind of cyclic loading. (3) An explicit equation is given for the variation of rotation capacity.

6.11-45 Taguchi, T., Sasagawa, A. and Minoshima, T., **On the strength and stiffness of beam-to-column connections in steel square-tube columns—Part II: Experimental research on the behavior of steel square-tube connections subjected to lateral force** (in Japanese), *Transactions of the Architectural Institute of Japan, 229,* Mar. 1975, 63-66.

In a previous paper, the authors reported on the shearing stress distribution of beam-to-column connections in steel square-tube columns, considering the variation of the distribution in walls of different thicknesses.

In this paper, the authors compare the theoretical values solved in the previous paper with experimental values. Three specimens, having the same wide-flange beams but three different types of columns, were tested. The widths of the tube walls were equal, but the width-to-thickness ratios were different. The specimen connections were subjected to bending, shear and thrust. It was found that the theoretical values of the shearing stress distribution on the boundaries of the cross section approximated the experimental values.

6.11-46 Taguchi, T. and Sasagawa, A., **On the strength and stiffness of beam-to-column connections in steel square-tube columns—Part III: Experimental research on reinforcement method of steel square-tube connections subjected to lateral force** (in Japanese), *Transactions of the Architectural Institute of Japan, 234,* Aug. 1975, 35-43.

An experiment was conducted to determine the most effective reinforcement for beam-to-column connections consisting of square-tube columns and rectangular-tube beams. The behavior of four different types of connections was studied. The specimen connections were subjected to antisymmetrical bending, shear and thrust. The connections having diaphragms penetrating to the tube-columns or having stiffeners alongside a beam-web exhibited a high degree of strength and stiffness.

The results of a theoretical study of the shearing stress distribution of square-tube columns having thin walls are discussed. Using a solution determined from this study, the authors obtain the limiting values of a thin wall. These values agree with the values of shear flow theory and with experimental values.

6.11-47 Sugiyama, H. and Suzuki, S., **Experimental study on the effect of racking test methods, sheathing materials and nailing upon the strength properties of the platform construction wall subjected to lateral force** (Part 2) (in Japanese with English summary), *Transactions of the Architectural Institute of Japan, 233,* July 1975, 39-50.

In a previous report, the authors discussed the results of a racking test of a platform construction wall covered with plywood or gypsum board sheathing without eliminating the influence of the rotation of the wall on the relative horizontal displacement of the upper point of the wall with respect to the lower point.

In this paper, similar test results are re-examined by eliminating the influence of the rotation of the wall on the relative horizontal displacement; i.e. the actual deformation of the wall due to bending and shearing is discussed. Using the A.S.T.M. method, the author discusses the action of vertical rods on the basis of the test results.

6.11-48 Morita, S. and Kaku, T., **Bond-slip relationship under repeated loading** (in Japanese), *Transactions of the Architectural Institute of Japan, 229,* Mar. 1975, 15-24.

The effects of the loading histories on the local bond-slip relationship were investigated, using reinforced concrete specimens in which the test bars were effectively contacted with concrete in a short length (four times the pitch of transverse rib).

It was observed throughout the tests that a small number of repetitions within a limited slip range did not have a significant effect on the bond-slip behavior at a larger slip in the subsequent cycles. However, once the peak slip was increased, a considerable reduction in bond was produced at a lower slip in the subsequent loading history.

From the test results, the basic bond-slip law under repeated loading was derived, which provided a satisfactory agreement with the experimental results. The basic bond-slip law was successfully applied to the prediction of the behavior of concentrically reinforced concrete prisms under repeated loading. It also was recognized that the degree of the concrete confinement surrounding the bar had a significant influence on the shape of the envelope curve of the bond-slip relationship.

● **6.11-49** Clough, R. W. and Li, F. L.-Y., **The dynamic behaviour of a first-story girder of a three-story steel frame subjected to earthquake loading,** *EERC 75-35,* Earthquake Engineering Research Center, Univ. of California, Berkeley, July 1975, 97. (NTIS Accession No. PB 248 841)

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

This report describes an experimental study of the behavior of a first-floor girder of a three-story steel frame subjected to earthquake loading. The instrumentation was designed to measure the force and deformation time histories of the girder.

The following aspects of the dynamic response are discussed: yielding at the girder ends in the inelastic test and the permanent deformation caused by the dead load effect of the concrete blocks; joint rotations; the dynamic moment capacity of the girder; hysteretic behavior; and ductility ratio.

● 6.11-50 Atalay, M. B. and Penzien, J., **The seismic behavior of critical regions of reinforced concrete components as influenced by moment, shear and axial force,** *EERC 75-19,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1975, 235.

Building response caused by moderate to severe earthquake excitation is often in the inelastic range; thus, to enable reliable predictions of overall performance, the energy absorption and failure characteristics of individual components must be established. For reinforced concrete frame buildings, the critical or yielding regions may occur in either or both the girders and columns subjected to various combinations of bending, shear, and axial load.

To determine the characteristics and modes of failure of columns under excitations causing degradations in stiffness, strength, and energy absorption, a series of twelve members simulating a column between inflection points above and below a floor level were designed and tested dynamically. The variable parameters introduced were (1) magnitude of applied axial load chosen to represent lower, intermediate, and upper story columns, (2) lateral reinforcement percentage chosen to study the influence of confinement on ductility, and (3) history of controlled lateral displacement chosen to determine the effects of rate and sequence of loading.

The results of these tests show that (1) increasing the applied axial load decreases the ultimate lateral displacement capacity, enhances the degrading mechanisms of strength, and stiffness, and, when the axial load is sufficiently high, causes changes in the failure modes from ductile flexure behavior to more brittle shear and buckling behavior, (2) decreasing the lateral reinforcement percentage decreases the ultimate lateral displacement capacity and enhances the degrading mechanisms. All experimental data from these tests have been analyzed and correlated to characterize the energy absorption, stiffness, and strength degradation mechanisms, the modes of failure, and the ductility capacities.

In addition to discussing the above-described test program and its correlation studies, this report presents a mathematical model for reinforced concrete columns which predicts force-deformation characteristics under inelastic cyclic conditions. This model can serve as a subelement in an overall mathematical model of a building.

● 6.11-51 Küstü, O. and Bouwkamp, J. G., **Behavior of reinforced concrete deep beam-column subassemblages under cyclic loads,** *EERC 73-8,* Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1975, 240. (NTIS Accession No. PB 246 117)

The results of an experimental program to study the behavior and collapse mechanism of reinforced concrete deep beam-column frames and to evaluate present U.S. code provisions, both with respect to design loads and design details, are presented. The behavior and failure modes of half-scale, two-story, beam-column subassemblages under cyclic-induced lateral displacements and constant axial column loads are investigated. The brittle failure due to an inadequate shear capacity of the column sections is noted. Recommendations to increase the lateral load resistance are presented. An analytical model to predict cyclic force-deflection behavior of beam-column subassemblages is developed. Two analytical hysteresis models associated with flexural and shear deformations of the members are described. The total behavior is obtained by superposition of flexural and shear components. "Pinching" of the hysteresis loops observed in the experiments and associated with the shear deformations is analytically reproduced. Analytical predictions are compared with the experimental results. Agreement in general proved to be satisfactory. Necessity to represent stiffness deterioration due to large number of load reversals (cyclic deterioration) in the analytical models is noted.

● 6.11-52 Clough, R. W. and Tang, D. T., **Earthquake simulator study of a steel frame structure, Vol. I: Experimental results,** *EERC 75-6,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1975, 293. (NTIS Accession No. PB 243 981)

This volume describes mainly the test results of the earthquake simulator study of a three-story single-bay moment-resistant steel frame structure using the 20 by 20 ft shaking table at the Earthquake Engineering Research Center at the Univ. of California, Berkeley.

Two series of tests were performed on the structure. In the first series, or Phase I study, the panel zones were underdesigned; then for the Phase II tests the panel zones were reinforced to make the girders and columns the weak elements of the structure.

The details of the structure are presented together with the instrumentation programs; the extent of the data collected in the tests is described. In addition to the small amplitude dynamic properties of the structure, pertinent test data on the mechanical behavior of the steel and the typical girder-to-column connection from coupon and pseudodynamic tests are appended.

The global responses of the structure under four types of table excitations are examined in seven test runs, two linear and five with significant nonlinear strains. From the four of these tests which used the El Centro 1940 N-S earthquake input, the detailed local responses of the structure such as force and deformation time histories, hysteresis diagrams and tabulated extreme values are shown. Key observations are made on the test results obtained in each of the seven runs.

Conclusions regarding the reliability of the test data and the general performance of the test structure are drawn. Recommendations are made concerning the future use of the shaking table in this type of test program.

● 6.11-53 Popov, E. P., Bertero, V. V. and Chandramouli, S., **Hysteretic behavior of steel columns**, *EERC 75-11*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1975, 229. (NTIS Accession No. PB 252 365)

This is the third and concluding report on the project "Inelastic Behavior of Beam-Column Subassemblages." The previous reports were titled *Inelastic Behavior of Steel Beam-Column Subassemblages* (Oct. 1971) and *Further Studies on Seismic Behavior of Steel Beam-Column Subassemblages* (Dec. 1973).

The results of experiments with eight specimens are given in the above two reports. These specimens were designed with strong columns, so as to have inelastic (hysteretic) behavior in the beams and the panel zones. In this report, emphasis is placed on the strong inelastic (hysteretic) action in the columns of steel beam-column subassemblages.

A total of six specimens were tested. In four of these, the columns were bent around their strong axes; in two, around their weak axes. The main objective of these tests was to determine the behavior of column plastic hinges subjected to random pseudostatic cyclic loading. Some tentative conclusions are drawn from the results of the analyses presented: (1) The application of moderate intensity inelastic cyclic moments to axially loaded columns is possible, provided the P/P_y ratio remains less than 0.5. At higher P/P_y ratios, there was a sharp drop in strength which was precipitated by flange buckling. (2) Panel zones can be effectively reinforced with doubler plates. Some inelastic action in such plates can be permitted since strain-hardening tends to arrest excessive deformations. (3) The moment capacity of columns in cyclic loading tends to be much greater than that calculated on the basis of the simple plastic theory. This is due to the strain-hardening of steel.

6.11-54 Sugiyama, H. and Suzuki, S., **Experimental study on the effect of racking test methods, sheathing materials and nailing upon the strength properties of the platform construction wall subjected to lateral force (Part I)** (in Japanese with English summary), *Transactions of the Architectural Institute of Japan*, 232, June 1975, 1-15.

Comparison of the strength properties of a wall panel determined from laboratory racking tests with those determined from full-scale tests of the same residential wall panel has been made.

Reported in this paper are the results of one of the tests. The influence of several variables (the type of racking test methods, the type of nails, nail spacing on the bottom plate, and the difference between single- and double-sheathing, when using gypsum board) on the strength and rigidity of the platform construction wall was taken into account. The wall was sheathed with plywood or gypsum board, and it was subjected to a racking load (horizontal force).

The rigidity of the wall panel was evaluated according to the relative horizontal movement of the upper point of the wall with respect to the lower, the horizontal movement including, to some extent, the effect of rotation of the wall. The rigidity obtained by omitting the effect of horizontal movement due to the rotation of the wall will be discussed later in a separate paper.

6.12 Deterministic Methods of Dynamic Analysis

● 6.12-1 Fried, I., **Notes on the finite element analysis of the axisymmetric elastic solid**, *International Journal of Solids and Structures*, **10**, *3*, Mar. 1974, 383-386.

A simple transformation of displacements considerably eases the explicit derivation of the finite element stiffness matrix for the axisymmetric elastic solid without causing a decline in the rate of convergence. The worsening of the condition of the global stiffness matrix caused by this transformation can be cured by scaling. A balanced numerical integration scheme maintaining the full rate of convergence is the one that integrates each term of the work and energy expressions to the order $2p - 2$, p being the degree of the complete polynomial in the shape functions.

● 6.12-2 Trujillo, D. M., **The direct numerical integration of linear matrix differential equations using Pade approximations**, *International Journal for Numerical Methods in Engineering*, **9**, *2*, 1975, 259-270.

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

A class of approximations to the matrix linear differential equation is presented. The approximations range, in accuracy, from the simplest forward difference scheme to the exact solution. The infinite series defining the exponential matrix is used to ascertain the accuracy of the various approximations. A clear distinction is made between approximations to the system equations and the forcing function, with the forcing term being represented by a piecewise linear function. Special application is given to the equations arising in structural dynamics of the form

$$\mathbf{M}\ddot{\mathbf{y}} + \mathbf{C}\dot{\mathbf{y}} + \mathbf{K}\mathbf{y} = \mathbf{g}(t)$$

For these structural dynamic equations, the measure of the energy of the system is used to analyze the stability of the numerical approximations.

● 6.12-3 Atluri, S. N., **Finite element-perturbation analysis of nonlinear dynamic response of elastic continua,** *Finite Element Methods in Engineering,* 581-595. (For a full bibliographic citation see Abstract No. 1.2-1.)

In this paper the problem of the nonlinear dynamic response of an elastic continuum is dealt with. A compatible displacement finite element model is employed for discretization in spatial coordinates to reduce the relevant partial differential equations of the problem to a system of coupled, nonlinear, ordinary differential equations which govern the behavior of nodal displacements in time. These equations are solved by means of a uniformly valid asymptotic expansion procedure. An example and discussion are included.

● 6.12-4 Argyris, J. H. *et al.,* **On numerical error in the finite element method,** *ISD-Report No. 177,* Inst. für Statik und Dynamik der Luft- und Raumfahrtkonstruktionen, Univ. of Stuttgart, 1975, 38.

Physical and numerical sources of errors in the finite element method are analyzed. A new type of iterative improvement is introduced where the residual is calculated in single precision. The iteration scheme is analyzed with respect to round-off errors and found to give significant improvement over existing direct approaches.

6.12-5 McNabb, J. W. and Muvdi, B. B., **Drift reduction factors for belted high-rise structures,** *Engineering Journal, AISC,* 12, *3,* 1975, 88-91.

In addition to the significance of the location of a belt truss for limiting drift in high-rise structures, another parameter is of major importance; this parameter, the drift reduction factor, is a function of the properties of the core as well as the properties and spacing of the exterior columns of the structure. The factor, which is developed mathematically, is designed for use in the analysis of ideal structures.

6.12-6 Rutenberg, A. and Heidebrecht, A. C., **Approximate analysis of asymmetric wall-frame structures,** *Building Science,* **10**, *1,* Mar. 1975, 27-35.

An approximate hand method is proposed for the lateral force analysis of asymmetric wall-frame structures having constant properties along the height. The coupled torsion-bending differential equations of equilibrium are decoupled using an orthogonal transformation. The deformations and stress resultants in the wall and frame assemblies are obtained by linearly combining the respective coefficients of each of the solved decoupled equations, with the stresses in the members being obtained by simple force distribution formulas. Nondimensional coefficients for deflection and stress resultants are given for a practical range of system parameters. The method is illustrated by a numerical example.

● 6.12-7 **Dynamic analysis of bridge structures subject to earthquake loads,** *R-7222-2432,* Agbabian Assoc., El Segundo, California, Dec. 1972, 2 vols., 690.

The overall objective of the study was to perform, for purposes of demonstration, state-of-the-art dynamic analyses for three typical reinforced concrete highway bridge structures subjected to earthquake-produced vibratory motion. The bridges studied were the San Bernardino County bridge, the San Jose bridge and the San Joaquin County bridge. Hypothesized worst-case earthquake-produced vibratory ground motions, compatible with the bridge sites and with bridge performance, were selected. Three-dimensional modelling of the bridge structures with simulation of hinges and expansion joints, structural damping, soil-structure interaction and inelastic material behavior was provided. After performance of the dynamic analyses, selected bridge columns were redesigned as required to prevent collapse of the bridges.

6.12-8 Tokuhiro, I., **Convergence of Fourier series solutions in the elastic analyses of the shear walls subjected to the various external plane forces,** *Transactions of the Architectural Institute of Japan, 211,* Sept. 1973, 15-26.

In this paper the author investigates by means of a Fourier series the elastic response of shear walls to plane forces. The relationship between the convergence and the number of terms in the series is demonstrated.

6.12-9 Bahar, L. Y., **Transfer matrix approach to elastodynamics of layered media,** *The Journal of the Acoustical Society of America,* **57**, *3,* Mar. 1975, 606-609.

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A transfer matrix approach is developed to determine the dynamic response of a layered elastic medium, loaded by arbitrary time-dependent tractions on the boundaries of the finite medium.

6.12-10 Harrison, T., Siddall, J. M. and Yeadon, R. E., **A modified beam stiffness matrix for interconnected shear walls,** *Building Science,* **10**, *2,* July 1975, 89–94.

In the stiffness analysis of plane interconnected shear walls, it is convenient to specify the degrees-of-freedom at nodal positions defined by the intersection of the centroidal axis of each interconnecting beam and the centroidal axes of the shear walls. These intersection points are positioned a finite distance away from the ends of each interconnecting beam.

A modified stiffness matrix is presented for an interconnecting beam which includes a rigid arm at each end to allow for this finite distance, rotational springs to account for the localized deformations which take place in the zones where the beam adjoins the shear walls and transverse shear springs to allow for shear deformations in the beam. The matrix is presented in a form which permits existing computer programs to be modified with ease.

A stiffness program employing this matrix is used to analyze a series of plane interconnected shear walls, previously tested by MacLeod, in which the beam depth was varied from model to model. The model showing the greatest sensitivity to localized effects was reanalyzed keeping the beam depth constant, but varying the number of stories and, consequently, the height of the structure.

The results are presented to show the importance of the rotational springs to the accuracy of the mathematical model, and they are compared with experimental evidence.

6.12-11 Abulgazin, R. K. and Astakhov, B. S., **Investigations of wave stresses in large dams** (Issledovanie volnovykh napryazhenii v tele bolshoi plotiny, in Russian), *Tekhnicheskie nauki, 17,* 1974, 117–121.

A new approach, which utilizes analytical and experimental techniques, is described for the calculation of seismic wave stresses arising in large dams. The results of theoretical investigations are compared to data obtained in model measurements. Quantitative relationships characterizing the development of seismic wave processes inside the dam during strong-motion earthquakes are obtained.

6.12-12 Beraya, A. G., **Seismic response of gravity dams by the finite strip method** (Raschet plotin gravitatsionnogo tipa na seismicheskie vozdeistviya metodom konechnykh polos, in Russian), *Seismostoikost sooruzhenii, 3,* 1974, 134–149.

The problem of calculating stresses in a dam is considered. The dam has a triangular or a trapezoidal profile on a rigid base, with the material of the dam assumed homogeneous, isotropic and linearly elastic. Both horizontal and vertical seismic forces as well as inertial loads on the dam are taken into account. The dam is partitioned into a series of cantilever beams, and then deflections due to internal stresses and external loadings are calculated, taking into account shear and tension in each finite element. Horizontal seismic loads are calculated according to the spectral theory of earthquake resistance as a function of the height of each finite element.

● 6.12-13 Bathe, K.-J., Ramm, E. and Wilson, E. L., **Finite element formulations for large deformation dynamic analysis,** *International Journal for Numerical Methods in Engineering,* **9**, *2,* 1975, 353–386.

Starting from continuum mechanics principles, the authors review and derive finite element incremental formulations for nonlinear static and dynamic analysis. The aim in this paper is a consistent summary, comparison, and evaluation of the formulations that have been implemented in the search for the most effective procedure. The general formulations include large displacements, large strains and material nonlinearities. For specific static and dynamic analyses in this paper, elastic, hyperelastic (rubber-like) and hypoelastic elastic-plastic materials are considered. The numerical solution of the continuum mechanics equations is achieved using isoparametric finite element discretization. The specific matrices that need to be calculated in the formulations are presented and discussed. To demonstrate the applicability and the important differences in the formulations, the solution of static and dynamic problems involving large displacements and large strains is presented.

● 6.12-14 Paz, M. and Dung, L., **Power series expansion of the general stiffness matrix for beam elements,** *International Journal for Numerical Methods in Engineering,* **9**, *2,* 1975, 449–459.

The general stiffness matrix for a beam element is derived from the Bernoulli-Euler differential equation with the inclusion of axial forces. The terms of this matrix are expanded into a power series as a function of the two variables: the axial force and the vibrating frequency. It is shown that the first three terms of the resulting series, which are derived in the technical literature from assumed static displacement functions, correspond respectively to the elastic stiffness matrix, the consistent mass matrix and the geometric matrix. Higher-order terms up to the second-order terms of the series expansion are obtained explicitly. Also a discussion is presented for establishing the region of convergence of the series expansion for the dynamic stiffness matrix, the stability matrix and the general stiffness matrix.

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● 6.12-15 Penzien, J., Chen, M.-C. and Tseng, W.-S., **Seismic response of highway bridges**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 176-185.

Mathematical models are described for determining the seismic response of reinforced concrete highway bridges. Two types are considered, namely, long structures having numerous spans and short structures having either a single or a limited number of spans. Both types are modelled to include elasto-plastic behavior of columns, nonlinear discontinuous behavior of expansion joints, and soil-structure interaction. Soil forces on abutments of the second type are generated through a finite element representation of the backfills. Seismic response characteristics are discussed for each type, and certain basic conclusions are deduced.

6.12-16 Mee, A. L. and Jordaan, I. J., **Simplified analysis of staggered wall-beam frames**, *Canadian Journal of Civil Engineering*, **2**, *3*, Sept. 1975, 305-320.

Simplified analyses of wall-beam frames, based on previously determined equivalent member stiffnesses, are given. The analyses are based on two approaches: (i) using the methods of difference calculus and (ii) using the continuum method, commonly used in shear wall analysis, in which the beams connecting the columns are replaced by a continuous connecting medium. It is shown that the analyses using difference and differential calculus are equivalent if an approximation of the column bending is introduced. Comparison of the proposed approximate methods with exact skeletal analysis shows excellent agreement. One conclusion of practical importance is that many analyses applied to shear walls, which are available in the literature, may be applied to wall-beam frames as well. It is suggested that in many cases it is possible in practice to neglect the column bending stiffness altogether, and details of an analysis based on this assumption are given.

● 6.12-17 Tani, J., **Dynamic instability of truncated conical shells under periodic axial load**, *International Journal of Solids and Structures*, **10**, *2*, Feb. 1974, 169-176.

Based on the dynamic version of Donnell-type basic equations, neglecting bending deformations before instability, the parametric instability of truncated conical shells subjected to periodic axial load is studied under four different boundary conditions. Applying Galerkin's method, the basic equations are reduced to a system of coupled Mathieu equations, from which the instability regions are determined by using Hsu's results. As a numerical example, instability regions for a completely clamped shell are determined for a relatively wide range of frequencies. The effects of static axial load as well as damping force on the instability regions also are examined.

6.12-18 Vendhan, C. P., **A study of Berger equations applied to non-linear vibrations of elastic plates**, *International Journal of Mechanical Sciences*, **17**, *7*, July 1975, 461-468.

The equations of motion based on Berger's hypothesis have been widely used in the nonlinear free vibration analysis of elastic plates mainly because of the simplicity of these equations. A rational mechanical basis for these equations has not yet been found. In the present paper, the variationally derived in-plane boundary conditions are examined with specific reference to the plates with edges free of in-plane stress resultants. It is shown that for this boundary condition the Berger equations can result in zero nonlinearity. A formal basis for the Berger equations is then critically discussed. Approximate modal equations governing the nonlinear, free, flexural vibrations of a few plate geometries are presented and compared with the von Kármán results. The numerical study reveals that the Berger equations do not yield consistently accurate results, and the results show an entirely different pattern of deformation. These observations may justify certain reservations regarding the general applications of the Berger equations.

● 6.12-19 Nagarajan, S. and Popov, E. P., **Non-linear dynamic analysis of axisymmetric shells**, *International Journal for Numerical Methods in Engineering*, **9**, *3*, 1975, 535-550.

Incremental equations of motion are derived from a Lagrangian variational formulation for the large displacement elastic-plastic and elastic-viscoplastic dynamic analysis of deformable bodies. The material constitutive behavior is described in terms of the symmetric Piola-Kirchhoff stress and Lagrangian strain tensors. Degenerate isoparametric elements, permitting relaxation of the Kirchhoff-Love hypothesis, are used in a finite element formulation specialized for the analysis of shells of revolution subjected to axisymmetric loading. The linearized incremental equations of motion are solved using direct integration procedures, with added accuracy obtained from application of equilibrium correction at each step. The effectiveness of the numerical techniques is illustrated by the dynamic response analyses carried out on a shallow spherical cap subjected to uniform external step pressure loadings.

● 6.12-20 Ross, C. T. F., **Finite elements for the vibration of cones and cylinders**, *International Journal for Numerical Methods in Engineering*, **9**, *4*, 1975, 833-845.

Elemental mass matrices are produced for the vibration of conical and cylindrical shells, based on a semi-analytical approach. Frequencies and modes of vibration are compared with existing solutions and also with experimental results obtained from other sources. Good agreement is found between theory and experiment for thin-walled circular cylinders and cones, a cone-cylinder combination, and a cooling tower model. A theoretical investigation also is made on the vibration of a circular cylinder when subjected to uniform pressure.

6.12-21 Srinivasan, R. S. and Ramachandran, S. V., **Vibration of generally orthotropic skew plates,** *The Journal of the Acoustical Society of America,* **57,** *5,* May 1975, 1113-1118.

This paper presents a numerical method for finding the natural frequencies and mode shapes of generally orthotropic clamped skew plates subjected to in-plane forces. As illustrations, two aspects are considered. First, the natural frequencies and mode shapes of a rhombic plate (without any in-plane forces) are determined for different orientations of the axes of orthotropy. Marked changes in the mode shapes, which are not easily predictable, are found to take place. Secondly, the influence of in-plane forces (both unidirectional tension/compression and uniform shear) on the natural frequencies is studied. The results indicate that in all cases but one the relationship between the square of the frequency and the in-plane force is nonlinear. The numerical method employed makes use of integral equations of beams with appropriate boundary conditions along the skew coordinates, for transforming the governing differential equation into a set of algebraic equations. These equations are then solved to find the eigenvalues and eigenvectors.

6.12-22 Rainer, J. H., **Damping in dynamic structure-foundation interaction,** *Canadian Geotechnical Journal,* **12,** *1,* Feb. 1975, 13-22.

Two methods of calculating the damping ratio for structures on compliant foundations are presented. One method employs the calculation of the system damping ratio from the dynamic amplification factor, the other the modal damping ratio from energy considerations. The numerical results for both methods are compared and interpreted. Three sources of damping are considered: interstory damping, radiation damping, and foundation material damping. The numerical results demonstrate that with the introduction of compliant foundations the damping ratio of the system can be larger or smaller than that of the corresponding fixed-base structure. Material damping in the foundation soil has been shown to contribute significantly to the overall damping ratio.

● 6.12-23 Nelson, F. C., **The role of closely spaced modes in the seismic response of equipment and structures,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 538-543.

An explanation is given of how to combine such things as the peak accelerations, displacements and stresses which result from a response spectrum analysis of nuclear power plant structures and equipment. The explanation is intended to be comprehensive in the sense that it is based on a general principle from which the absolute sum, the square root of the sum of the squares, and the double-sum modal recombination rules can be extracted as special cases. The purpose of such a comprehensive explanation is to convince design engineers that these rules—in particular the recently proposed double-sum rule—are logical in their formulation and, therefore, sensible in their application.

● 6.12-24 Kubo, J. T. and Nelson, R. B., **Modal analysis for impact of layered plates,** *Journal of the Engineering Mechanics Division, ASCE,* **101,** *EM1,* Proc. Paper 11133, Feb. 1975, 45-56.

An analysis is presented of the plane strain response of an arbitrarily layered elastic plate to surface impact loads of specified distribution over the plate surface and in time. Each layer has specified orthotropic material properties, with coincident material and plate axes. The method is based on the extended Ritz technique and employs a normal mode procedure to accurately predict the motion through the plate thickness of stress waves generated by the impact load. The case of impact on an isotropic plate is studied in detail, both with the present method and other methods based on the exact elasticity theory to indicate the accuracy and convergence properties of this method. The procedure is applied to the case of a two-layer plate, where each layer is assigned orthotropic elastic properties typical of a unidirectional boron-epoxy composite. The stress waves generated by a normal surface impact are presented to indicate both the quality and quantity of information that can be generated by the analysis. A tension wave that trails the initial compression wave is shown to exist.

● 6.12-25 Keer, L. M. and Chantaramungkorn, K., **Some comments on an approximation by Awojobi,** *International Journal of Solids and Structures,* **10,** *1,* Jan. 1974, 15-19.

In several papers Awojobi has used an approximation technique to solve the problems of the forced oscillations of a body on an elastic stratum. This paper compares his approximate solution for axially symmetric torsion with numerical results derived from an integral equation developed by Gladwell. The approximate results show acceptable accuracy for the prediction of resonant frequencies. The prediction of resonant amplitude is limited by the nature of the approximate method.

● 6.12-26 Capurso, M., **A displacement bounding principle in shakedown of structures subjected to cyclic loads,** *International Journal of Solids and Structures,* **10,** *1,* Jan. 1974, 77-92.

Continua, or structures composed of elastic-perfectly plastic material subjected to cyclic loads that vary within the shakedown limits, are considered. A theorem bounding the residual deflection at any point is presented. Some numerical examples are discussed.

6.12-27 Distefano, N. and Jain, A., **A Cauchy system in the linear theory of thin shells of revolution,** *International Journal of Engineering Science,* 13, 2, Feb. 1975, 173–182.

The differential equations of the linear theory of thin shells of revolution, as derived by A. Kalnins in terms of eight fundamental state variables from the Reissner-Meissner equations, and subject to appropriate boundary conditions, are reduced to a system of integro-differential equations of the Riccati-type subject to initial conditions. The reduction is meaningful on theoretical grounds since it offers an alternative description of a boundary value problem in terms of a Cauchy system and valuable from a numerical point of view because of the inherent stability of the resulting sequential algorithms. A discussion on rigorous and computational aspects closes the presentation.

● 6.12-28 Rodrigues, J. S., **Node numbering optimization in structural analysis,** *Journal of the Structural Division, ASCE,* **101**, *ST2*, Proc. Paper 11117, Feb. 1975, 361–376.

An algorithm is presented to produce an optimum node numbering system for a structure to be analyzed by the finite element method, reducing computer time and storage needs if "band solution" methods are used for solving the system of equations. Only nonzero off-diagonal elements of the connectivity matrix defining the topology of the structure are stored in a rectangular integer array. For every nonzero element causing the largest current bandwidth, the algorithm finds a pair of rows (and columns) to be interchanged in such a way that the bandwidth is either reduced or left unchanged. The process continues until the bandwidth is reduced either to the minimum or to the largest acceptable value, depending on the input parameters. A list of new node numbers is produced. New code numbers (listings of the elements) are also produced and punched in a set of cards ready to replace the old set.

● 6.12-29 Srirangarajan, H. R. and Dasarathy, B. V., **Decoupling in non-linear systems with two degrees of freedom,** *Journal of Sound and Vibration,* 38, *1*, Jan. 8, 1975, 1–8.

The problem of decoupling a class of nonlinear two degree-of-freedom systems is studied. The coupled nonlinear differential equations of motion of the system are shown to be equivalent to a pair of uncoupled equations. This equivalence is established through transformation techniques involving the transformation of both the dependent and independent variables. The sufficient conditions are presented on the form of the nonlinearity, for the case where the transformed equations are linear. Several cases of particular interest also are illustrated.

● 6.12-30 Srinivasan, R. S. and Sankaran, S., **Vibration of cantilever cylindrical shells,** *Journal of Sound and Vibration,* **40**, *3*, June 8, 1975, 425–430.

The integral equation technique has been used to determine the natural frequencies of free vibration of cantilever cylindrical shells. For this analysis, Donnell's shell theory has been adopted. Numerical results have been obtained and compared with those of other investigators.

● 6.12-31 Croll, J. G. A., **Kinematically coupled nonlinear vibrations,** *Journal of Sound and Vibration,* **40**, *1*, May 8, 1975, 77–85.

The dynamic response of a simple two degree-of-freedom mechanical analog is investigated to illustrate the nature of mode interaction that exists for systems in which the stiffness against vibrations in one mode is sensitive to the amplitude of the vibration response in the second possible mode. A finite difference approximation of the nonlinear differential equations controlling the small nonlinear interactive dynamics of this model is used to determine the responses for a representative range of nondimensional parameters. These numerical experiments confirm the phenomenological predictions of an earlier paper: that over a range of excitation energy inputs dependent upon the damping characteristics and the separation between the two uncoupled natural frequencies of small vibration, a multiplicity of resonant frequencies will be observed to occur in the first mode. In some situations and above a certain super-critical energy input level, it becomes impossible to observe the resonance that would be predicted from an uncoupled small vibration analysis of this first mode.

● 6.12-32 Epstein, H. I., **Vibrations with time-dependent internal conditions,** *Journal of Sound and Vibration,* **39**, *3*, Apr. 8, 1975, 297–303.

This paper deals with extending an existing method that solves time-dependent boundary conditions to include time-dependent internal conditions. The solution derived is applicable to most vibration problems as well as to many other systems governed by linear differential equations. The solution is accomplished by treating internal points subjected to a time-dependent condition as internal "boundary" points. The method of solution is illustrated in this paper by considering the dynamic response of a Bernoulli-Euler beam.

● 6.12-33 Vendhan, C. P. and Das, Y. C., **Application of Rayleigh-Ritz and Galerkin methods to non-linear vibration of plates,** *Journal of Sound and Vibration,* **39**, *2*, Mar. 22, 1975, 147–157.

The difference between the three variational equations of motion and the dynamic analog of the von Karman

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equations governing the nonlinear vibration of plates is considered in the context of the Rayleigh-Ritz and Galerkin methods. The nonlinear free vibrations of two types of plates with in-plane constraints are considered as examples. In the analysis a single mode expansion is assumed for the transverse displacement and the in-plane inertia terms are neglected. The convergence of the nonlinear time period is studied by increasing the number of terms in the modal expansions for the in-plane displacements. It is observed that the Rayleigh-Ritz and Galerkin approximations converge from opposite directions, thus suggesting a possible approach to bound the solutions on either side. The general significance of this observation is discussed.

● 6.12-34 Kounadis, A. N., **Dynamic response of cantilevers with attached masses,** *Journal of the Engineering Mechanics Division, ASCE,* **101,** *EM5,* Proc. Paper 11616, Oct. 1975, 695–706.

Using generalized functions, the frequency equation for free vibrations of a cantilever beam-column having rotational and translational springs at its support, and carrying concentrated masses, is established in matrix form and is evaluated numerically. The effect of rotatory inertia of the concentrated masses also is included. Moreover, a procedure for establishing the mode shapes is presented. Finally, the differential equation for the modal amplitudes of forced motion is established.

● 6.12-35 Kausel, E., Roesset, J. M. and Waas, G., **Dynamic analysis of footings on layered media,** *Journal of the Engineering Mechanics Division,* ASCE, **101,** *EM5,* Proc. Paper 11652, Oct. 1975, 679–693.

A finite element formulation for the dynamic analysis of circular footings resting on or embedded in layered soil strata is presented. The formulation provides excellent results; it accurately reproduces the lateral radiation effects through a consistent energy transmitting boundary, which is an extension of that suggested by Waas and Lysmer for two-dimensional problems. Because the boundary can be placed directly at the edge of the footing without loss of accuracy, it also provides savings in storage requirements and time of computation over other solutions. The analysis must be performed in the frequency domain; arbitrary transient loading conditions are then handled using fast Fourier transformation techniques.

● 6.12-36 Ural, O., **Finite element method and computer programs,** *Finite Element Methods in Engineering,* 549–563. (For a full bibliographic citation see Abstract No. 1.2-1.)

This paper considers the finite element method from a user's point of view and discusses the relevance and the areas of application of the available computer programs based on the method. The results are presented of a survey taken at United States and Canadian universities to determine the procedures used to teach the finite element method.

● 6.12-37 Cheng, F. Y., **Finite element analysis of structural instability by association of pulsating excitations,** *Finite Element Methods in Engineering,* 597–609. (For a full bibliographic citation see Abstract No. 1.2-1.)

An analytical procedure is presented for determining the dynamic instability and response of framed structures subjected to pulsating axial loads, time-dependent lateral forces, or foundation movements. Included in the analytical work are the instability criteria of a structural system, the finite element technique of structural matrix formulation, and the computer solution methods.

6.12-38 de Silva, C. W., **A technique to model the simply supported Timoshenko beam in the design of mechanical vibrating systems,** *International Journal of Mechanical Sciences,* **17,** *6,* June 1975, 389–393.

A simple technique for introducing the effects due to shear deformation and rotatory inertia in the design of transversely vibrating beams is developed using the state-space analysis of modern control theory. The control of beam vibration using linear and rotatory dampers is considered as a special case.

● 6.12-39 Thomas, J. and Abbas, B. A. H., **Finite element model for dynamic analysis of Timoshenko beam,** *Journal of Sound and Vibration,* **41,** *3,* Aug. 8, 1975, 291–299.

This paper presents for the first time a finite element model with nodal degrees-of-freedom that can satisfy all the forced and natural boundary conditions of a Timoshenko beam. The mass and stiffness matrices of the element are derived from kinetic and strain energies by assigning polynomial expressions for total deflection and bending slope. The superiority of this element is illustrated by comparing the results with those given by various investigators using other element models.

● 6.12-40 Paramasivam, P., Yeh, C. S. and Nassim, S., **Dynamic analysis of building frames,** *Journal of Sound and Vibration,* **41,** *1,* July 8, 1975, 103–112.

This paper presents a modified and extended iterative method for determining the response of building frames to dynamic loads and the consequent forces induced in the frame members. This procedure takes into account the different individual joint rotations, instead of assuming them to be equal. The proposed method can be applied with the aid of a desk calculator or a small computer and is especially suitable for practicing design engineers. Numerical examples are presented, and the results are compared with those obtained from other methods.

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● **6.12-41** Dasarathy, B. V., **Equivalent linear models for non-linear non-autonomous systems,** *Journal of Sound and Vibration,* 42, *4,* Oct. 22, 1975, 447–452.

Equivalence between a class of nonlinear nonautonomous systems of second order and a linear model of lower order is established through a differential transformation relation. It is shown that this equivalence can be established only under a certain constraint on the nonlinear functional parameters of the given system. The equivalence automatically leads to the first integral, which then can be analyzed further to obtain the response of the system. The feasibility of obtaining closed-form solutions through such analysis is illustrated by considering certain sub-classes of systems. Further, the practical value of the technique is demonstrated through an example.

● **6.12-42** Utku, S., **Systematic substructuring,** *Journal of the Structural Division, ASCE,* **101**, *ST4,* Proc. Paper 11244, Apr. 1975, 717–730. (For an additional source, see Abstract No. 6.12–52, *AJEE,* Vol. 4.)

In many large structural analysis problems, due to the limitations in digital computer hardware, one is forced to partition the problem into smaller units to complete the analysis. When the partitioning is done by the analyst, it is called substructuring. The paper is concerned with those partitionings that stem from the need to solve a large problem with a small computer. Considering only the displacement method of analysis, the important parameters of rational partitioning are displayed and the means of systematic partitioning are examined. Algorithms are given to improve the present practice of partitioning from the standpoint of total computing cost.

● **6.12-43** Noor, A. K. and Fulton, R. E., **Impact of CDC STAR-100 computer on finite element systems,** *Journal of the Structural Division, ASCE,* **101**, *ST4,* Proc. Paper 11216, Apr. 1975, 731–750. (For an additional source, see Abstract No. 6.12–53, *AJEE,* Vol. 4.)

A study is made of the impact of the projected major hardware and software features of the CDC STAR-100 computer on the overall organization and design of components of finite element structural analysis systems. The major features considered include virtual memory and the pipeline processing or streaming capability. The effective utilization of the STAR capabilities in finite element systems requires: (1) The consistent use of modular design concepts in all phases of the finite element system; and (2) the design of the different modules and processors to exploit the STAR pipeline processing capabilities. The paper concludes with two examples showing the anticipated gain in speed over the CDC 6600 to be obtained by using the STAR streaming capability. These examples are computation of element stiffness matrices and solution of banded symmetric equations. In both cases order of magnitude gain in speed may be obtained.

● **6.12-44** Meyer, C., **Special problems related to linear equation solvers,** *Journal of the Structural Division, ASCE,* **101**, *ST4,* Proc. Paper 11223, Apr. 1975, 869–890. (For an additional source, see Abstract No. 6.12–54, *AJEE,* Vol. 4.)

This paper describes and compares the various techniques developed for the solution of large sets of equations, with particular emphasis on file handling operations. The brief summary of the problems associated with boundary conditions and multiple-load cases is followed by a survey of research on reanalysis techniques, which have gained increased importance in recent years in the field of structural engineering. Problems associated with numerical error are examined, whereby the structural engineer's preference for physical interpretations of mathematical phenomena is respected. A comprehensive bibliography, divided into various categories covering the entire field of linear equation solvers, concludes the paper.

● **6.12-45** Sun, C.-K., **Hybrid techniques for inelastic dynamic problems,** *Journal of the Structural Division, ASCE,* **101**, *ST4,* Proc. Paper 11221, Apr. 1975, 891–919. (For an additional source, see Abstract No. 6.12–58, *AJEE,* Vol. 4.)

Hybrid computer programming techniques are used to study the free vibration behavior of certain inelastic systems and their dynamic responses due to earthquake excitations. The methods of solution are examined in detail. Sources of error and cost comparison with digital computation results are presented. Computed results confirm the conclusions obtained from theoretical predictions. It has been found that P-Δ effect parameters have significant influence on the dynamic behavior of inelastic systems. These parameters, which are in dimensionless forms, are related to the masses, the lateral stiffnesses, and the height of each story of the structure.

● **6.12-46** Dawe, D. J., **High-order triangular finite element for shell analysis,** *International Journal of Solids and Structures,* 11, *10,* Oct. 1975, 1097–1110.

A curved-shell finite element of triangular shape is described. The element is based on conventional shell theory expressed in terms of surface coordinates and displacements. Each of the three surface displacement components is independently represented by a two-dimensional polynomial of constrained-quintic order giving the element a total of 54 degrees-of-freedom. Two particular geometric forms of the element are considered, viz. doubly-curved shallow and circular cylindrical. The high level of accuracy that can be achieved using few elements is demonstrated in a range of problems where comparison is made with previous finite element solutions.

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● **6.12-47** Rabizadeh, R. O. and Shore, S., **Dynamic analysis of curved box-girder bridges,** *Journal of the Structural Division, ASCE,* **101,** *ST9,* Proc. Paper 11561, Sept. 1975, 1899–1912.

The finite element technique is used for the forced vibration analysis of horizontally curved box girder bridges. Annular plates and cylindrical shell elements are used to discretize the slab, bottom flanges and webs. Rectangular plate elements and pin-jointed bar elements are used for diaphragm discretization. A vehicle, as the applied time varying forcing function, is simulated by two sets of concentrated forces, having components in the radial and transverse directions and moving with constant angular velocities on circumferential paths of the bridge. The effect of centrifugal forces is considered and the effect of damping of the bridge is neglected in the analysis. The mass condensation technique is used to reduce the number of coupled differential equations obtained from the finite element method. The resulting differential equations are solved by the linear acceleration method. A number of bridges with practical geometries are analyzed and impact factors are calculated.

● **6.12-48** Raggett, J. D., **Estimating damping of real structures,** *Journal of the Structural Division, ASCE,* **101,** *ST9,* Proc. Paper 11554, Sept. 1975, 1823–1835.

Described in this paper is a method to obtain equivalent modal viscous damping ratios from stiffness and energy dissipation properties of structural components. Specifically, modal viscous damping ratios are computed as the weighted sum of component energy ratios (ratio of energy dissipated to peak potential energy per cycle of motion) weighted by the ratios of component to total peak potential energies. Component energy ratios may be estimated from vibration studies of the individual components or similar structures made exclusively of the component materials. Component potential energies may be computed from component stiffness matrices and modal deflections. A great simplification is that total peak potential energy may be computed as half the natural circular frequency squared for mode shapes normalized such that the generalized mass equals unity. Modal viscous damping ratios are computed for four example structures, all having reinforced concrete frames with gypsum wallboard partitions. Predicted and measured damping ratios vary from 2 to 5%.

● **6.12-49** Beskos, D. E. and Boley, B. A., **Use of dynamic influence coefficients in forced vibration problems with the aid of Laplace transform,** *Computers and Structures,* **5,** *5/6,* Dec. 1975, 263–269.

The use and importance of dynamic stiffness influence coefficients in flexural forced vibrations of structures composed of beams are described. The dynamic forces can be either harmonic or general transient forces. The dynamic influence coefficients are defined in the Laplace transform plane, are computed there and are given in tables for uniform beams under various end conditions. The dynamic response is obtained, in general, by a matrix inversion in the Laplace transform plane and a numerical inversion, based on interpolation concepts, of the transformed solution. Structural examples of forced vibrations of a simple beam and a rigid frame illustrate the use of dynamic coefficients and demonstrate their advantages over other known methods in accuracy, simplicity of formulation and speed of computation.

● **6.12-50** Sun, C. T. and Huang, S. N., **Transverse impact problems by higher order beam finite element,** *Computers and Structures,* **5,** *5/6,* Dec. 1975, 297–303.

A higher-order beam finite element is derived and shown to be very efficient in solving the transient dynamic problem. The finite element thus developed is then applied to impact problems concerning the response of beams to striking elastic masses. Due to the local indentation, the motion of the beam is nonlinearly coupled with the motion of the mass. An efficient iterative procedure is proposed in this paper to integrate the time variable. Both elastic impact and impact with permanent indentations are considered. The finite element solutions are found to be in good agreement with some existing solutions.

● **6.12-51** Fried, I. and Malkus, D. S., **Finite element mass matrix lumping by numerical integration with no convergence rate loss,** *International Journal of Solids and Structures,* **11,** *4,* Apr. 1975, 461–466.

Using numerical integration in the formation of the finite element mass matrix and placing the movable nodes at integration points causes the mass matrix to become lumped or diagonal (block diagonal) with the optimal rate of energy convergence retained.

● **6.12-52** Chan, P. C. K., Heidebrecht, A. C. and Tso, W. K., **Approximate analysis of multistory multibay frames,** *Journal of the Structural Division, ASCE,* **101,** *ST5,* Proc. Paper 11302, May 1975, 1021–1035.

An approximate analysis of multistory, multibay elastic frames subjected to static lateral loads is developed. The approximation is made that the axial deformations of the columns have hyberbolic sine variation across the width of the building. Assuming points of contraflexure at the mid-heights of the columns and at the midspans of the connecting beams and using the energy approach permits the development of a set of two coupled differential equations. These can be reduced to one equation, the solution of which can be written explicitly for each loading condition. Examples comparing results with those obtained by the "exact" stiffness matrix method show that the method yields acceptably accurate deflections, axial

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stresses, and column shears. Design curves for the rapid determination of the parameters are included.

● 6.12-53 Nagarajan, S. and Popov, E. P., **Non-linear finite element dynamic analysis of axisymmetric solids,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3,** *4,* Apr.-June 1975, 385-399.

The subject of this paper is the finite element analysis of axisymmetric solids subjected to axisymmetric static and dynamic loading, and taking into account material as well as geometric nonlinearities. A general Lagrangian formulation forms the basis for the incremental equations of motion, which are solved using direct integration methods. Solution accuracy is improved by applying equilibrium correction loads at each step. Finite element discretization is achieved through the use of quadrilateral plane stress and axisymmetric elements with incompatible modes added for improvement of the element flexural characteristics. Several numerical examples are presented to demonstrate the effectiveness of the developed computer program.

● 6.12-54 Henshell, R. D. and Ong, J. H., **Automatic masters for eigenvalue economization,** *International Journal of Earthquake Engineering and Structural Dynamics,* **3,** *4,* Apr.-June 1975, 375-383.

In dynamic analyses using the finite element method, very large matrices are derived. The size of the matrices is usually reduced using an eigenvalue economization method. This paper describes an automatic technique for selecting the optimum variables to be kept as masters using the economization method. Some examples are presented and these lead to an empirical statement about expected accuracy.

● 6.12-55 Melosh, R. J., **Integration of linear equations of motion,** *Journal of the Structural Division, ASCE,* **101,** *ST7,* Proc. Paper 11444, July 1975, 1551-1558.

This paper presents features of implementation of a transfer algorithm for solving linear ordinary differential equations using a digital computer. It shows results of applications to simple problems. Tests show the algorithm requires less computer time per step than other representative direct methods. It does not need adaptive error control. Variable time step logic is not required for integration to be efficient and effective. The consequences of these advantages are evidenced by a reduction in computer time for a Runge-Kutta integration by a factor of 4000, while obtaining answers of improved accuracy. The examination shows that the efficiency and accuracy of the algorithm dictate use of an integration step size of the order of one-fifth the time of the shortest system period represented. The relation between the period and the number of calculations to generate the transfer matrix provides a reliable means of ensuring that the appropriate time step is being used.

● 6.12-56 Holze, G. H. and Boresi, A. P., **Free vibration analysis using substructuring,** *Journal of the Structural Division, ASCE,* **101,** *ST12,* Proc. Paper 11788, Dec. 1975, 2627-2639.

The method of substructuring is developed and applied to the solution of free vibration problems for large structural systems. Modifications to the substructure stiffness and mass matrices permit the substructure mode shapes to more accurately conform to the complete system mode shapes. These modifications account for the elastic and inertial effects of the surrounding structure on each substructure. Computational algorithms are described which determine the substructure mode shapes associated with the lowest natural frequencies. These algorithms are based on an iterative scheme with an automatic starting method. The synthesis method for the determination of the system mode shapes from the substructure mode shapes is demonstrated. An example problem is solved, and the solution is compared to that obtained by a conventional method.

● 6.12-57 Al-Mahaidi, R. S. and Nilson, A. H., **Coupled shear wall analysis by Lagrange multipliers,** *Journal of the Structural Division, ASCE,* **101,** *ST11,* Proc. Paper 11732, Nov. 1975, 2359-2366.

A special finite element technique is described which permits interconnection of line elements in flexure and first-order plane stress elements. Continuity of displacements and rotations at the junction of the two types of elements is satisfied by imposing certain constraint conditions through the use of Lagrangian multipliers. The method can be employed to analyze coupled shear walls as well as frame-shear wall systems. Accuracy is checked by analyzing a coupled shear wall system with three degrees of mesh refinement. Results are further compared with those from a conventional finite element scheme, which idealizes the coupling beams by plane stress elements. The proposed method is shown to be more accurate and more efficient than the conventional method.

● 6.12-58 Noor, A. K. and Voigt, S. J., **Hypermatrix scheme for finite element systems on CDC STAR-100 computer,** *Computers and Structures,* **5,** *5/6,* Dec. 1975, 287-296.

A study is made of the adaptation of the hypermatrix (block matrix) scheme for solving large systems of finite element equations on the CDC STAR 100 computer. Discussion is focused on the organization of the hypermatrix computation using Cholesky decomposition and the mode of storage of the different submatrices to take advantage of the STAR pipeline (streaming) capability.

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Consideration also is given to the associated data handling problems and the means of balancing the data transfer and the central processing unit times in the solution process. Numerical examples are presented showing anticipated gain in cpu speed over the CDC 6600 to be obtained by using the proposed algorithms on the STAR computer.

● 6.12-59 Paz, M. and Cassaro, M. A., **Determination of seismic response for prestressed concrete beams**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 381-388.

The seismic response of structural beam systems is affected by the existence of self-strains, which may be induced by temperature gradients, mechanical actions or prestressing. The fundamental dynamic properties such as natural frequencies and mode shapes are influenced by the presence of these strains. As a consequence, the response of the structure changes to the extent that the self-strains change the dynamic characteristics of the structure and to the extent that these characteristics are relevant in the interaction of a particular structure with a given ground motion.

This paper presents a detailed study of prestressed concrete beams subjected to seismic motions. The homogeneous differential equations of motion are expressed in terms of the stiffness, mass, and geometry matrices and a parameter accounting for the self-strain effect. The solution of the resulting eigenvalue problem is used to write the modal equations into which the desired ground motion is applied.

The final response is obtained from the appropriate shock spectrum and the application of the root mean square superposition technique. The disturbing action produced by the ground motion of the El Centro earthquake of 1940 is applied to several prestressed concrete beams in which the amount of self-strain is varied as a parameter.

● 6.12-60 Ramesh, C. K. and Dantwala, N. M., **The inelastic response of a 20-storey reinforced concrete frame to Koyna earthquake**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 331-338.

The inelastic response of a 20-story reinforced concrete building frame subjected to the north-south component of the Koyna accelerogram is evaluated, using a step-by-step numerical integration of the governing equations of motion. To establish the reliability of the method, the trend of these results is compared with the results of two other studies of the inelastic response of reinforced concrete frames that were subjected to El Centro earthquake ground motions.

The simple, straightforward numerical integration technique used in this paper is applicable to any linear, nonlinear, elastic or inelastic system. In particular, it provides a reliable and fast means for predicting the dynamic inelastic response and for evaluating the stresses of any complex system. The results obtained with the technique are described.

● 6.12-61 Cheng, F. Y., **Matrix analysis of complex dynamic structures**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 267-278.

This paper presents an external dynamic structural matrix method for computerized analysis of the eigenvalue problem of a wide class of complex structures. The method is based on the linear behavior of coupling longitudinal and flexural vibrations. The dynamic matrix is based on the structural configurations and the internal stiffness of the members. The stiffness coefficients of the constituent structural members with various boundary conditions are derived and then plotted in curves. Axial deformations can have a remarkable effect on the eigenvalues of a structure composed of members with a relatively high radius of gyrations. Free vibration problems of all types of structures can be solved expeditiously using the method.

● 6.12-62 Barria, D., Guendelman, T. and Monge, J., **Use of transfer matrices in seismic analysis of tall buildings**, *Fifth Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 279-284.

The use of transfer matrices in the seismic analysis of tall buildings is presented. It is assumed that most tall buildings can be represented by a mathematical model consisting of a pure shear beam and a pure bending beam fixed at their bases and continuously connected through the height. The overall stiffness parameters characterizing the model are generated by addition of the individual values of each building substructure. A linear differential equation is formed and solved using the transfer matrix discretization technique. The method gives fairly accurate results compared to standard matrix analysis solutions and provides a fast tool for preliminary design.

For the case of tall buildings regular in plan graphs, defining the main results of the analysis as a function of the stiffness parameters, are presented. Their use could further reduce computational efforts. Two examples show some applications of the method.

● 6.12-63 Herman, H., **Extension of Lanczos' method of fundamental eigenvalue approximation**, *Journal of Applied Mechanics*, **42**, Series E, 2, June 1975, 484-489.

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A method, introduced by Lanczos for the approximate determination of fundamental eigenvalues of one-dimensional continuous systems, is extended to permit the determination of higher eigenvalues as well; and a modification is introduced which yields better accuracy for the same number of approximating equations. Illustrations are presented demonstrating applications of the method to systems with discontinuities and to the frequency determination in nonlinear oscillation problems.

● 6.12-64 Taylor, D. L. and Kane, T. R., **Multiparameter quadratic eigenproblems,** *Journal of Applied Mechanics,* **42,** Series E, 2, June 1975, 478–483.

This paper contains an analytical theory for the study of the eigensystem of a multiparameter quadratic eigenproblem. Previous work in this general area has focused mainly on first-order eigenproblems. In the present work, eigenvalues and eigenvectors are expressed in the form of infinite series in which parameters entering the elements of various matrices play the roles of independent variables, and it is shown how the coefficients may be evaluated. The methods of derivation are given in sufficient detail to allow extension to either higher derivatives or higher-order eigenproblems. Among the results presented are formulas for the second derivatives of eigenvectors, which have not been presented previously. Formulas applicable to special cases of first-order eigenproblems are given also.

● 6.12-65 Fu, F. C. L. and Nemat-Nasser, S., **Response and stability of linear dynamic systems with many degrees of freedom subjected to nonconservative and harmonic forces,** *Journal of Applied Mechanics,* **42,** Series E, 2, June 1975, 458–463.

Dynamic systems whose response can be characterized by a set of linear differential equations with harmonic coefficients which are proportional to a small parameter are considered. These systems are such that the corresponding autonomous sets of equations, which are obtained by setting the parameter equal to zero, are defined by nonself-adjoint linear differential operators; i.e., they correspond to dynamic systems subjected to nondissipative nonconservative forces. For these systems, general asymptotic solutions are developed and their stability is examined. An interesting feature of these solutions is that, when the exciting frequency is close to, say, twice a suitable eigenfrequency, or when it is close to the sum or the difference of two suitable frequencies of the autonomous system, then the asymptotic solution will involve negative fractional powers of the parameter. Hence, the nonsecular asymptotic solution, in general, may not reduce to the solution of the autonomous system as the parameter goes to zero. Another interesting feature of the present results is that the addition of small suitable harmonic forces does indeed stabilize an inherently unstable nondissipative nonconservative dynamic system, except when the frequency of the harmonic force resonates with one or several of the frequencies of the autonomous system in either a subharmonic or a combinational-type oscillation.

● 6.12-66 Park, K. C., **An improved stiffly stable method for direct integration of nonlinear structural dynamic equations,** *Journal of Applied Mechanics,* **42,** Series E, 2, June 1975, 464–470.

The behavior of linear multistep methods is evaluated for application to structural dynamics problems. By examining the local stability of the currently popular methods as applied to nonlinear problems, it is shown that the presence of historical derivatives can cause numerical instability in the nonlinear dynamics even for methods that are unconditionally stable for linear problems. Through an understanding of the stability characteristics of Gear's two-step and three-step methods, a new method requiring no historical derivative information is developed. Superiority of the new method for nonlinear problems is indicated by means of comparisons with currently popular methods.

● 6.12-67 Chen, J. C. and Wada, B. K., **Criteria for analysis-test correlation of structural dynamic systems,** *Journal of Applied Mechanics,* **42,** Series E, 2, June 1975, 471–477.

A rational criterion for structural dynamic analysis-test correlation is established by using a matrix perturbation technique. This criterion can be used for the verification of an analytical model by the test results. Also, the same technique can be applied to update the analytical results by using the test results without repeating the entire analytical procedure. A sample problem is used to demonstrate this technique. Very satisfactory results are obtained with only the first-order perturbation solution included for transient loading. For periodic loading, higher-order perturbation solutions are needed to achieve the same accuracy.

● 6.12-68 Lindberg, H. E. and Kennedy, T. C., **Dynamic plastic pulse buckling beyond strain-rate reversal,** *Journal of Applied Mechanics,* **42,** Series E, 2, June 1975, 411–416.

A large deflection, elastic-plastic numerical theory (SABOR/DRASTIC 6) is used to investigate dynamic buckling motion beyond strain-rate reversal in cylindrical shells under radial impulse. It is found that the mode number of the most amplified harmonic is smaller than predicted by the simple analytic tangent modulus theory because of the increased stiffness after strain-rate reversal, neglected in the simple theory. Nevertheless, the simple theory gives reasonable estimates for threshold buckling impulses. In buckling well beyond threshold (about three times the threshold impulse in a thin shell, radius-to-thickness ratio of 120), plastic deformation becomes more localized at the buckle crests, but compressive strain continues to dominate

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so that a simple plastic hinge postbuckling analysis would be inadequate. Accuracy of the numerical theory is confirmed by comparison with experiment (asymmetric loading below buckling threshold and symmetric loading above) and with the tangent modulus theory prior to strain-rate reversal.

● 6.12-69 Kunukkasseril, V. X. and Ramakrishnan, R., **Dynamic response of circular bridge decks,** *International Journal of Earthquake Engineering and Structural Dynamics,* 3, *3,* Jan.-Mar. 1975, 217-232.

A method has been developed for the study of the dynamic response of curved bridge decks on the basis of plate equations in polar coordinates. A general solution for the forced motion of annular sector plates has been obtained by the method of spectral representation. The specific problem of a moving force on the bridge deck is discussed in detail. A method for obtaining the static response from dynamic analysis is suggested. Numerical results are presented to illustrate the influence of the speed of travel of the force and of the physical parameters of the bridge decks on the deformation. A detailed discussion on the numerical results also is included.

● 6.12-70 Tseng, W. S. and Penzien, J., **Seismic analysis of long multiple-span highway bridges,** *International Journal of Earthquake Engineering and Structural Dynamics,* **4,** *1,* July-Sept. 1975, 3-24.

Mathematical models and three-dimensional nonlinear dynamic analysis procedures are described for determining the seismic response of long, curved (or straight), multiple-span, reinforced concrete highway bridges. Under the action of strong earthquakes, the columns (or piers) of such structures may experience large cyclic inelastic deformations of a coupled form. Also, cyclic slippage of the Coulomb type can take place in the expansion joints of the deck causing multiple impacts and separations to occur. These separations may be sufficiently large to cause tensile yielding of the longitudinal expansion joint restrainer bars (or cables) and, if not controlled, can permit deck spans to fall off their supports, resulting in partial or total collapse of the structure. In this paper, a three-dimensional elasto-plastic mathematical model suitable for representing the coupled inelastic flexural behavior of reinforced concrete columns under cyclic deformations is presented along with a nonlinear mathematical model for simulating the nonlinear discontinuous behavior of expansion joints. The procedures used for nonlinear seismic response analysis are described, and a numerical example is given to illustrate the method.

● 6.12-71 Danay, A., Gluck, J. and Gellert, M., **A generalized continuum method for dynamic analysis of asymmetric tall buildings,** *International Journal of Earthquake Engineering and Structural Dynamics,* **4,** 2, Oct.-Dec. 1975, 179-203.

The paper presents a continuum method for dynamic analysis of asymmetric tall buildings with uniform cross section in which the horizontal stiffness is provided by shear walls and columns of arbitrary shape and layout, coupled by horizontal beams.

The equations of motions are formulated in variational terms, including axial strain energy. Numerical solutions, obtained by using finite time differences and infinite polynomials, are presented for the response of a twenty-story building with six shear walls to an impact load and earthquake accelerations.

It is shown that omission of the axial deformations results in a substantially distorted pattern of behavior, some of its effects being: (1) Overestimation of the bending stiffness of the coupled shear walls, with corresponding changes in their stiffness ratios. (2) Underestimation of the periods of the principal modes, with a corresponding change in the dynamic response. (3) Distortion of the magnitude, form, time of onset and coupling of the maximum displacements. (4) Pronounced change in the shear force and moment diagrams for the shear walls, the beams and the building as a whole.

● 6.12-72 Takizawa, H., **Non-linear models for simulating the dynamic damaging process of low-rise reinforced concrete buildings during severe earthquakes,** *International Journal of Earthquake Engineering and Structural Dynamics,* **4,** *1,* July-Sept. 1975, 73-94.

This paper is a study of idealizing a planar reinforced concrete frame as a nonlinear dynamic system for the purpose of simulating its inelastic behavior during severe earthquakes. After having estimated the restoring force characteristics of all constituent members by experimental means (represented, for example, by a group of empirical equations), it is possible to estimate the nonlinear characteristics of the complete structure and to trace the damaging process for each constituent member under a given ground motion disturbance. However, this technique, which is directly based on member-level properties, generally requires rather laborious computational procedures; for practical reasons it is necessary to develop a simplified model, reducing the required calculation without losing the substance of the mechanical phenomena. Thus the reliability of simplification by conventional shear modelling is examined in direct comparison with the response results from rigorous modelling. It is concluded that the shear modelling generally yields an inadequate and, in many cases, erroneous result. The primary cause leading to this discrepancy is identified and, based on this discussion, a more appropriate modelling as simple as conventional shear modelling is proposed.

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● 6.12-73 Bahar, L. Y. and Sinha, A. K., **Matrix exponential approach to dynamic response,** *Computers and Structures,* 5, *2/3,* June 1975, 159–165.

The matrix exponential technique, widely used in modern control theory, is adapted as a direct integration procedure for predicting the dynamic response due to discrete inputs. A sample problem the exact solution of which is known is solved analytically, and the response is compared with the Wilson method, as well as with the matrix exponential. The method is then applied to the response of a nuclear structure subjected to an earthquake excitation. Results indicate that the matrix exponential method is well suited for problems where the input data is in digitized form.

● 6.12-74 Fam, A. and Turkstra, C., **A finite element scheme for box bridge analysis,** *Computers and Structures,* 5, *2/3,* June 1975, 179–186.

A finite element scheme for static and free vibration analysis of box bridges with orthogonal boundaries and arbitrary combinations of straight and horizontally curved sections is described. In-plane, bending and coupling action as well as anisotropic element properties are included in the analysis. A variety of special purpose elements are developed to suit the behavior characteristics of thin box sections. The program has been found to reliably predict deflections and stresses for a variety of analytical and experimental test cases.

6.12-75 Williams, R., Yeow, Y. T. and Brinson, H. F., **An analytical and experimental study of vibrating equilateral triangular plates,** *Experimental Mechanics,* **15**, *9,* Sept. 1975, 339–346.

A general description and a historical discussion of trilinear coordinates are given. These coordinates are then used to develop the solution of a simply-supported freely vibrating equilateral triangular plate. The solution gives fundamental frequencies, mode shapes, nodal lines and a general expression for displacements.

An experimental program is described to validate the analytical solution. Nodal lines, mode shapes and displacements are determined by holographic interferometry and compared to theoretical results. Excellent agreement is obtained. A second experimental technique, a fiber-optic device, is used to determine displacements with the results being compared to the displacements obtained by both theoretical and holographic analysis.

● 6.12-76 Kirkley, O. M. and Murtha, J. P., **Earthquake response spectra for offshore structures,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2356, May 1975, 207–214.

A method for adapting existing earthquake response spectrum techniques to the analysis and design of offshore structures is presented. The offshore structure is modeled as a lumped-parameter system and a nonlinear fluid resistance law is assumed. The nonlinear hydrodynamic drag effects are approximated satisfactorily by a linearizing technique—except for the high-frequency portion of the response spectrum where a special relation is shown. Rules are given for the construction of approximate earthquake response spectra using design estimates for the maximum values of ground displacement, velocity, and acceleration and certain characteristics of the structure. With the procedures set forth in this paper, earthquake response spectra that include fluid inertia and drag effects can be developed and used for offshore structures, and much of the information already available on response spectrum techniques for land-based structures can easily be adapted for use by designers of ocean structures. Examples are given of the application of the method to offshore structures.

● 6.12-77 Filson, J. J. and Perez y Perez, L., **Application of spectral methods to non-linear dynamic systems,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. II, Paper No. OTC 2263, May 1975, 209–222.

The paper describes a technique whereby spectra of irregular seas are applied to dynamic analysis of nonlinear offshore systems to produce response and response spectra. It employs the fast Fourier transform (FFT) to produce irregular excitation records from a specified sea spectrum. Response is determined in the time-domain and response spectra are formed from the response record, again using the FFT. The basic methods used are described and application of the method is discussed. An example application is presented of the dynamic response of a jack-up drilling unit which shows some uses of the results. The intent of the paper is to show how spectral methods can be used to produce analytic results where experimental methods have previously been necessary.

● 6.12-78 Belytschko, T. and Schoeberle, D. F., **On the unconditional stability of an implicit algorithm for nonlinear structural dynamics,** *Journal of Applied Mechanics,* **42, Series E,** *4,* Dec. 1975, 865–869.

In this paper an implicit Newmark β-method with iterations for nonlinear structural dynamics is described; the algorithm is identical to standard algorithms except that a new convergence criterion is employed. A discrete energy is defined and it is shown that this discrete energy is bounded regardless of the size of the time step; this is a sufficient condition for the unconditional stability of the algorithm for nonlinear material problems. Numerical examples are given for problems with both geometric and material nonlinearities.

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● 6.12-79 Bassily, S. F. and Dickinson, S. M., **On the use of beam functions for problems of plates involving free edges,** *Journal of Applied Mechanics,* **42, Series E,** *4,* Dec. 1975, 858–864.

The inadequacy of beam vibration mode shapes when used in the Ritz method to obtain approximate solutions for flexural problems concerning plates involving free edges is demonstrated. A new set of functions, related to beam mode shapes, is postulated which allows considerably more accurate treatment of such plates. Several numerical examples concerning static deflection and free vibration of plates involving free edges are examined. These examples illustrate the applicability and accuracy of the new functions and further demonstrate the inadequacy of the ordinary beam functions.

● 6.12-80 Benvenuto, E. *et al.,* **A large displacement seismic analysis of monodimensional elastic structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 73, 5. (For a full bibliographic citation see Abstract No. 1.2–8.)

Starting from a general treatment of the nonlinear dynamic behavior of slender monodimensional elastic structures, in the large displacement field, an approach is presented for the seismic analysis of guyed towers. After a comprehensive exposition of the general equations governing the problem, a solution technique is developed. In the solution technique, using some technically simplified assumptions, a finite-difference discretization is carried out with respect to space, whereas a Runge-Kutta numerical integration is performed with respect to time. A description of the computer program concludes the paper.

● 6.12-81 Sotirov, P., Tzenov, L. and Boncheva, H., **Dynamic behaviour of complex structural systems,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 76, 4. (For a full bibliographic citation see Abstract No. 1.2–8.)

The purpose of the present paper is to study the dynamic behavior of complex structural systems composed of a comparatively rigid body (stair well towers) and a flexible frame. The method of analysis is explained. The interaction effect between the two main parts of the structure is discussed. A stiffness evaluation was performed by using the bending-shear theory individually for each part of the structure. The stiffness matrix of the entire structure is obtained by superposition, taking into account the soil-structure interaction. The eigenvalue analysis is performed, and the results are compared with the experimental data.

● 6.12-82 Rutenberg, A. and Tso, W. K., **Contribution to earthquake analysis of coupled shear walls,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 78, 5. (For a full bibliographic citation see Abstract No. 1.2–8.)

A dynamic spectral analysis of uniform coupled shear walls under earthquake excitation is carried out by means of the continuum approach. Using the equations of equilibrium in terms of horizontal and axial displacements, the orthogonality property of the normal modes is derived. The modal equations with their participation factors are obtained by applying the eigenfunction expansion technique. Graphical presentations of the modal participation factors and base moment coefficient for a wide range of structural configurations enable the engineer to evaluate the seismic loading for the first three modes with a minimum of computational effort.

● 6.12-83 Thakkar, S. K. and Arya, A. S., **Inelastic response of arches under earthquake motions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 69, 8. (For a full bibliographic citation see Abstract No. 1.2–8.)

A method of dynamic analysis is presented for computing the response of arches under the simultaneous action of permanent vertical loads, along with the horizontal and vertical components of ground motions. The method takes into account nonlinear effects of large deflections as well as inelasticity of the material. Arches having any shape, arbitrary distribution of mass and stiffness and any boundary conditions can be analyzed by this method. The elastic linear, elastic nonlinear and inelastic responses of a fixed circular arch are compared with each other to demonstrate the significance of nonlinear analysis.

● 6.12-84 Veletsos, A. S., Erdik, M. O. and Kuo, P. T., **Response of structures to propagating ground motions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 63, 22. (For a full bibliographic citation see Abstract No. 1.2–8.)

The response of simple structures supported on individual footings is analyzed for propagating ground motions. The results are compared with those computed on the assumptions that the foundation experiences: (1) a uniform translation only, and (2) a uniform translation coupled with a rigid body rotation without shearing distortion. The waveforms considered include a pulse-type excitation and an actual earthquake record. The effects of the more important parameters influencing the response are discussed, and the conditions under which the wave propagation effects are of sufficient importance to warrant consideration in design are identified. For particular cases, simple expressions are included for evaluating the maximum deformation of the most critically stressed corner column.

● 6.12-85 Ovünç, B. A., **Analysis of structures subjected to horizontal and vertical earthquake,** *Proceedings, Fifth*

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European Conference on Earthquake Engineering, Vol. 1, Paper No. 59, 15. (For a full bibliographic citation see Abstract No. 1.2-8.)

The analysis of structures subjected to horizontal and vertical earthquake motion is performed by using the continuous mass matrix method. The real, continuous distribution of the masses over the constituent members of the structures is taken into account without recurring to the lumping of the masses at the joints. If a concentrated mass exists on the system, its point of application is considered as a joint of the system. The damping is taken into account as a percentage of the critical damping in order that the modal analysis can be applied. The governing modes for horizontal and vertical earthquake motions are determined. The effects of the ratio of masses of the beams to the masses of columns and the ratio of the rigidities of the beams to the rigidities of the columns of the structures are investigated.

● 6.12-86 Fajfar, P., **Numerical analysis of multistorey structures**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 79, 6. (For a full bibliographic citation see Abstract No. 1.2-8.)

The basic principles of a general but simple and economical method for the static, dynamic and stability analysis of nonsymmetrical multistory structures are presented. The method is applicable to the majority of tall buildings. It is possible to take into account any groundplan arrangement of stiffening elements, different heights of stories, the changing of static and dynamic characteristics throughout the height of a building, the stiffening elements of different heights, and the elastic foundation. To illustrate the method, a numerical example is presented.

● 6.12-87 Kartsivadze, G. N. and Chachava, T. N., **Response of complex structures to seismic motion**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 85, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The paper deals with the response of complex structures to seismic motion. The following two problems are considered: seismic vibrations of expanded structures that rest upon the ground at several local points and selection of the design (least favorable) direction of seismic motion for a complex structure. The analytical design method is described for the solution of these problems, and some general regularities are discussed.

● 6.12-88 Taskovski, B., Paskalov, T. and Petrovski, J., **Formulation of mathematical model of a multistory building, based on the full-scale experiments**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 101, 4. (For a full bibliographic citation see Abstract No. 1.2-8.)

Because of the necessity to accurately define the geometrical and physical parameters of complex structural systems, it is difficult to determine the dynamic response of such systems. Existing analytical procedures are unable to provide proper definitions of these parameters. It is possible that the experimental technique of forced vibration studies on full-scale structures could provide data for a sufficiently accurate evaluation of the structural parameters, as well as for a mathematical model formulation.

In this paper, a study of the dynamic response of a 14-story prefabricated prestressed concrete structure is presented, and evaluation of the equivalent structural parameters is described.

● 6.12-89 Pekau, O. A., **Seismic behaviour of structures with taper**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 86, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper the problem of variable stiffness and uniform mass common to tall beam-column construction is studied. Dynamic characteristics and expected seismic response for variable stiffness shear beams and a series of framed structures are formulated and compared. Results indicate that parameters basic to seismic response of tapered structures are approximated reasonably well by variable stiffness shear beam behavior. This implies that shear beam response data may be usefully applied to framed structures and seismic design.

● 6.12-90 Monakhenko, D. V., **Modelling of hydraulic structures subjected to seismic loads**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 106, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The conditions for generalized (operator-functional) modelling of dynamic problems of linear elasticity and viscous elasticity theories are obtained. In contrast to the similarity criteria, the conditions defined herein permit the establishment of a one-to-one correspondence of the stress state of the model and the prototype under dissimilar external forces and different elastic and viscous elastic properties of model and prototype materials.

● 6.12-91 Aktan, A. E., **Effects of history on biaxial resistance of a r/c section**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 97, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The effects of curvature disturbances on the biaxial moment resistance envelope of a square, tied column section subjected to its balanced axial force were investigated. The disturbances were applied at the service load range, resulting in nonmonotonic straining of the section. A

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discrete analysis technique, incorporating the stress-strain relations and hysteretic behavior of the constitutive materials, was employed. The results are discussed with reference to the application of the resistance envelope to the multidimensional response analysis of concrete.

● 6.12-92 Distefano, N. and Salmonte, A., **Modelling and identification of nonlinear dynamic behavior of steel frames**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 98, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper, an identification procedure is developed to determine the parameters associated with a Ramberg-Osgood model of a three-story steel frame from displacement and acceleration records. The results are compared with those obtained using a nonlinear viscous model in terms of a differential equation.

● 6.12-93 Baron, F., Hamati, R. E. and Pang, S.-H., **Seismic characteristics of long multi-span highway bridge types**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 148, 14. (For a full bibliographic citation see Abstract No. 1.2-8.)

The influences of various girder types and joint articulations on the seismic responses of long multispan highway bridges are reported. The girder types are of cast-in-place and precast concrete construction and steel twin-box sections. Various types of expansion joints and girder tc piercap connections are considered. A 7400 ft long bridge, composed of 43 spans founded on various soil conditions, including thick mud and deep water sections, is studied. Response characteristics are determined for light, moderate, and severe ground motions of both sections. Time-history and spectral analyses based on design and response spectra are performed for two- and three-dimensional models. Interactions of water mass, soils, footings, and piling groups are considered.

● 6.12-94 Baron, F. and Pang, S.-H., **Analytical modeling for seismic studies of extended bridge structures**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 147, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The paper presents general and specific observations concerning the analytical modeling of long multispan bridges for seismic studies. General observations are made with reference to the mathematical expressions and the physical interpretations of the inertia, damping, and stiffness characteristics of such structures. They also refer to the various kinds of analyses that are conducted in seismic studies. Special considerations are given to the modeling of two- and three-dimensional characteristics of dynamic response. Several techniques based on mathematical or physical interpretations are presented for simplifying the models by reducing the degrees-of-freedom. Specific consideration is given to the analytical modeling employed to represent various joint articulations, the interaction of water with piers and piling groups, and the interaction of soil, footings, piling groups, and superstructure.

6.12-95 Lombardo, V. N., **Design of arch dams for seismic loadings on the basis of accelerograms** (Raschet arodinykh plotin na seismicheskie vozdeistviya, zadannye akselerogrammoi, in Russian), *Seismostoikost bolshikh plotin*, 1973, 66-73.

A method of calculating seismic stresses in arch dams of arbitrary profile is outlined. The calculation is based on numerical solution of the wave equations of the theory of shells using the explicit difference method. The results obtained are compared with those given by the spectral theory.

6.12-96 Matsuoka, O. and Iijima, T., **The general theory of rods with micro-deformations (Part II)** (in Japanese), *Transactions of the Architectural Institute of Japan, 237*, Nov. 1975, 77-86.

In this paper, some applications of a previous paper are analyzed, e.g. (1) analysis of a tall symmetric frame of one bay subjected to a horizontal concentrated load, (2) analysis of a vierendeel plate subjected to a sinusoidally distributed load, and (3) increment theory: analysis of vierendeel frame with initial stress and buckling loads of vierendeel frame.

Many practical but important problems are analyzed easily by use of the continuum mechanics theory of rods with microdeformations. This theory then may be extended and applied to many important engineering problems.

6.12-97 Kato, S., Murata, T. and Matuoka, S., **Dynamic buckling of rotational shells by combined finite element and mode superposition method—Part 3: Axisymmetric dynamic buckling analyses of non-shallow and clamped spherical shells and asymmetric dynamic buckling analyses of shallow clamped shells subjected to the simultaneous action of a uniform lateral pressure and a concentrated force on the apex** (in Japanese), *Transactions of the Architectural Institute of Japan, 235*, Sept. 1975, 19-25.

An efficient and practical system to analyze the dynamic nonlinear problems of rotational shells is developed. The system consists of the finite element and the mode superposition methods, and is effectively applied to solve the dynamic buckling of spherical shells under the simultaneous action of a uniform load and a concentrated force on the apex. The critical step loads required to produce snapping are numerically determined for shell parameter λ from 10 to 18. The axisymmetrical snapping is found to be localized around the apex. The axisymmetric dynamic buckling loads, composed of a uniform lateral pressure and a concentrated force, being 2.42% of the total load, are compared with the static buckling loads obtained from experiments by many authors and are shown to be in exact agreement with the lower bound of the experiments.

6.12-98 Kato, S., Murata, M. and Matsuoka, O., **Dynamic buckling analyses of rotational shells by means of a combined finite element and mode superposition method—Part 2: Dynamic buckling analyses of a shallow clamped spherical cap subjected to the simultaneous action of a uniform lateral pressure and a concentrated load on the apex** (in Japanese), *Transactions of the Architectural Institute of Japan, 228*, Feb. 1975, 25-30.

The object of the present paper is to formulate an efficient method for nonlinear dynamic analyses of rotational shells by the combined use of the finite element method and the mode superposition method. Effects of geometrical variations are taken into consideration.

A shallow spherical cap having a clamped edge subjected to lateral pressure is analyzed for λ = 5, 6, 7, 8 and 9, and the results are found to be in fair agreement with those given by other authors. For various ratios, the shell, subjected to the simultaneous dynamic action of a uniform pressure and a concentrated load on the apex, is investigated. The results show a large amount of reduction of the dynamic buckling load due to a slight concentrated load. The interaction formula for the dynamic buckling of the lateral pressure and the concentrated load is discussed.

6.12-99 Bakhabov, G., and Matkarimov, A. Kh., **Investigations of vibrations of viscoelastic underground pipelines due to seismic excitations** (Issledovanie kolebani vyazkouprugikh podzemnykh turboprovodov pri seismicheskikh vozdeistviyakh, in Russian), *Voprosy mekhaniki, 15*, 1974, 117-129.

Transverse and longitudinal vibrations of viscoelastic pipelines due to seismic excitations are investigated. The equations obtained are solved using an averaging method. Justification of the use of the averaging method is given. Formulas for calculating stresses and strains at arbitrary cross sections are obtained.

6.12-100 Mavlyanov, T., **Response of viscoelastic cylindrical shells to plane seismic waves** (Povedenie vyazkouprugikh tsilindricheskikh obolochek pod deistviem ploskoi seismicheskoi volny, in Russian), *Voprosy mekhaniki, 15*, 1974, 136-143.

The response of viscoelastic cylindrical shells to plane seismic pressure waves is investigated. An integral-differential equation describing deformations of the shells is obtained and solved using the Laplace transform.

6.12-101 Vekua, T. P., **Numerical solution of the inverse problem in the theory of structural earthquake resistance for elastic systems with two degrees-of-freedom** (Chislennoe reshenie obratnoi zadachi teorii seismostoikosti dlya uprugoi sistemy s dvumya stepenyami svobody, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 55-66.

A numerical solution of the inverse problem in engineering seismology is given for a system with two degrees-of-freedom without additional restrictions. The case of an elastic system with a single degree-of-freedom subjected to harmonic vibrations is considered. The dependence of maximum values of strain, velocity and acceleration on angular frequency and logarithmic damping decrements is investigated using the Pacoima Dam accelerograms of the 1971 San Fernando earthquake, and assuming that the soil layer or structure can be regarded as a cantilever system with known masses.

6.12-102 Esaiashvili, D. V., **Calculation of seismic forces and stresses in shells with deformable supporting structure** (Opredelenie seismicheskikh sil i napryazhennogo sostoyaniya v obolochkakh s uchetom deformativnosti podderzhivayushchikh konstrucktsii, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 76-88.

Results of the theoretical analysis of seismic loads on shells with deformable supporting structures are given. A technique is outlined for calculating the natural frequencies and mode shapes of vibration together with seismic loads and stresses in the presence of horizontal or vertical seismic excitation. Vibrations of the entire shell as a whole are allowed. The method of finite intersecting strips is used. The shell is approximated by a three-dimensional lattice with concentrated forces acting between its elements. Coupled free and forced vibrations are considered. The spectral method is used to calculate radial and tangential seismic forces. The technique was employed in the design of the roof of the sports hall of the Tbilisi plastic factory.

6.12-103 Volchkov, Yu. M. and Korobeinikov, S. N., **Calculation of dynamic response of cylindrical shell in plastic-elastic deformation using implicit finite-difference methods** (Reshenie dinamicheskoi zadachi krugovoi tsilindricheskoi obolochki pri uprugo-plasticheskikh deformatsiyakh po neyavnoi konechno-raznostnoi skheme, in Russian), *Dinamika sploshnoi sredy, 14*, 1973, 37-43.

An implicit finite-difference computational scheme is considered and applied to the calculation of the dynamic behavior of a plastic-elastic cylindrical shell. Since the equations are nonlinear, at each step in the calculation a successive approximation is used. The calculations performed on a BESM-6 computer showed this method to be stable for those steps during which the computer was running; the successive approximations converge rapidly.

6.12-104 Shishkov, S., **Investigations of earthquake response of buildings using accelerograms** (Issledovanie povedeniya zdanii pri seismicheskikh vozdeistviyakh s pomoshchyu aktselerogramm, in Bulgarian, with Russian and German abstracts), *Stroitelstvo*, **21**, *3*, 1974, 15–17.

A brief survey of the most important methods used in the study of the earthquake response of buildings is given. The fundamental points of methodology are discussed, and a computer program for ICL4-50 is worked out for the study of the earthquake resistance of buildings. The earthquake parameters used are the coordinates of accelerogram peak points. A 20-story frame building is studied. The values for the seismic forces and horizontal displacements obtained are compared with those prescribed by codes in operation in Bulgaria.

6.12-105 Kato, S., Murata, M. and Matsuoka, O., **Dynamic buckling analyses of rotational shells by means of a combined finite element and mode superposition method–Part 1: Formulation of the nonlinear dynamic analyses** (in Japanese), *Transactions of the Architectural Institute of Japan*, *227*, Jan. 1975, 47–55.

The object of this paper is to formulate an efficient method for nonlinear dynamic analyses of rotational shells by the combined use of the finite element method and the modal superposition method.

In Part 1, a formulation of the nonlinear dynamic analyses is presented for general shells of rotation. The nonlinear equations in the two tangential directions are solved with use of the finite element method and the two tangential displacements are determined as functions of the assumed lateral displacement. Then, the dynamic nonlinear modal equations are derived. The effects of geometrical imperfections are taken into consideration.

6.12-106 Fujimoto, M. *et al.*, **Nonlinear three dimensional analysis of steel frame structure** (in Japanese with English summary), *Transactions of the Architectural Institute of Japan*, *227*, Jan. 1975, 75–90.

The incremental method, a nonlinear method of dynamic analysis, is discussed. This method also is referred to as the initial stress method, which has developed on the basis of a stationary principle of incremental potential energy. In this method, prime consideration is given to the incremental potential energy, which is taken as the difference between strain energy, expressed as a quadratic form of the incremental displacement, and potential energy of the external force, which is dispersed through displacement of the part subjected to external force. By applying a variational method to the quadratic form, a simultaneous linear equation in the incremental displacements is obtained. This equation is reformulated and solved by means of a step-by-step method and an iteration method.

6.12-107 Ohta, Y., **Application of optimization technique into a few important problems in earthquake engineering–Part I: Estimation of underground structure at SMAC site in Hachinohe City** (in Japanese), *Transactions of the Architectural Institute of Japan*, *229*, Mar. 1975, 35–41.

An optimization technique under the unconstrained condition is presented for estimating ground motion and the dynamic characteristics of a building during an earthquake. An attempt is made to estimate the dynamic response of the underground structure at the SMAC site in Hachinohe City to the strong motion of the 1968 Tokachi-oki earthquake recorded there. Seismic records at the free surface and at a depth of 50 m are used. The structural parameters optimized are S-wave velocities and Q-values. Diagrams of the optimization procedure are presented. The optimal spectral ratio between two seismometer positions shows good agreement with observations. The physical significance of the results also is investigated.

6.12-108 Ishimaru, S., **Ductility factor control method: On the frame system having strong-columns and weak-girders** (No. 1) (in Japanese with English summary), *Transactions of the Architectural Institute of Japan*, *232*, June 1975, 17–28.

The equivalent linearization method, which utilizes the concept of ductility factor control, is used to analyze a frame having strong columns and weak girders. It also is shown how this method can be applied to analyze multistory frames.

6.12-109 Hughes, T. J. R., Hilber, H. M. and Taylor, R. L., **A reduction scheme for problems of structural dynamics**, *SESM 75-9*, Div. of Structural Engineering and Structural Dynamics, Univ. of California, Berkeley, Sept. 1975, 35.

A method for reducing the size of finite element systems in dynamics is presented. The technique is based upon a variational theorem in which it is admissible to describe the inertial properties of structures by way of independent displacement, velocity and momentum fields. This theorem allows us to construct reduced systems for problems in structural mechanics which retain the full rate of convergence of systems employing "consistent" mass matrices. In particular, we are able to make precise the engineering intuition regarding the "inefficiency" of rotatory degrees-of-freedom in dynamics, i.e. for the common beam, plate and shell elements, rotatory degrees-of-freedom may be entirely eliminated while retaining full rate of convergence. An error analysis of the scheme and numerical examples are presented.

● **6.12-110** Chen, M.-C. and Penzien, J., **Analytical investigations of seismic response of short, single, or multiple-**

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span highway bridges, *EERC 75-4*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Jan. 1975, 183. (NTIS Accession No. PB 241 454)

This report is the third in a series to result from the study, "An Investigation of the Effectiveness of Existing Bridge Design Methodology in Providing Adequate Structural Resistance to Seismic Disturbances," sponsored by the U.S. Dept. of Transportation, Federal Highway Admin. Descriptions are given of the analytical investigations of the seismic response of short, single or multiple-span highway bridges of the type where soil-structure interaction effects are important.

Six different mathematical model elements are incorporated into the computer program which possesses the capability of performing linear or nonlinear analyses. Finite element modelling is used for the backfill soils. Bridge deck, piers, and abutments are modelled using prismatic beam elements. A frictional element is used to model the discontinuous behavior at the interface of backfill soils and abutments. Discontinuous-type expansion joint elements are also included. Linear spring elements provide flexibility at the vertical soil boundaries. The soil foundation flexibilities under columns are established using elastic halfspace theory. In the nonlinear mathematical model, the effects of separation and impact at the interface between abutments and backfills, the yielding at concrete columns and backfill soils and slippage at the expansion joints are taken into consideration.

Parameter studies are first carried out considering a rigid wall backfill soil system. A short, stiff, three-span bridge is then investigated with full soil-structure interaction effects included. Finally, based on the analytical results, a general conclusion regarding the capability of the analyses is deduced.

● 6.12-111 Tang, D. T., **Earthquake simulator study of a steel frame structure, Vol. II: Analytical results,** *EERC 75-36*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1975, 214. (NTIS Accession No. PB 252 926)

This study presents mainly the development of mathematical models and the verification of response predictions for a three-story single-bay moment-resistant frame structure, using the experimental results observed for the structure tested on the 20 ft x 20 ft shaking table at the Earthquake Engineering Research Center at the Univ. of California, Berkeley.

The overall background and the test design for the research program which consisted of two series of experiments are described. In the first series, or Phase I study, the panel zones of the structure were overdesigned. In the Phase II study, the panel zones were reinforced to make the girders and columns the weak elements of the structure. Test results ranging from the small-amplitude vibration properties to the global and local nonlinear responses of the structure, which were used in the analytical studies, are summarized and discussed.

Three mathematical models, called Model A, B and C respectively, were developed. However, the model, Model C, which takes into account the interaction between the shaking table and the test structure was considered a rational one from which the pitching motion of the shaking table could adequately be described. By means of Model C, with the damping and the element yield criteria being treated as the main parameters to be prescribed in each computer analysis, the predicted global and local time history responses for both linear and nonlinear tests of the structure subjected to simulated El Centro earthquake motions were compared with those observed during the two phases of tests. The nonlinear response prediction based on a linear analysis procedure was demonstrated for the structure, using an increased viscous damping for the model. The ability of the model in predicting the floor displacement responses of the structure excited by table motions other than the simulated El Centro earthquakes was investigated. Data correlation for the small-amplitude vibration test results was also made.

Finally, conclusions are drawn regarding the performance of the test structure, the data correlation and the effect of the parameters of the mathematical models on the response prediction of the structure.

● 6.12-112 Mondkar, D. P. and Powell, G. H., **Static and dynamic analysis of nonlinear structures,** *EERC 75-10*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Mar. 1975, 152. (NTIS Accession No. PB 242 434)

This report presents the theoretical and computational procedures which have been applied in the design of a general purpose nonlinear computer code for static and dynamic analysis of nonlinear structures. Using the principle of virtual displacements, incremental equations of motion for structures undergoing large displacements and strains are first derived, using the Lagrangian description of deformation. These equations of motion are then discretized using the finite element displacement formulation, and the element characteristics, including "linear" and "nonlinear" stiffness matrices, are derived for the particular case of a two-dimensional isoparametric finite element. Physical nonlinearity due to material behavior is introduced for elasto-plastic materials, and the constitutive laws for commonly used elasto-plastic models are described. A computational algorithm for state determination of such path dependent materials is presented. Various procedures for solution of the nonlinear equations are reviewed. An integration procedure for dynamic analysis, based on step-

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by-step methods with optional iteration, is described. Control parameters suitable for setting up a flexible solution strategy, as implemented in the general purpose computer code, are outlined. Results for a series of example analyses are presented to demonstrate the capabilities of the computer code and to investigate the stability and accuracy of various solution strategies.

● **6.12-113** Dasgupta, G. and Sackman, J. L., **An alternative representation of the elastic-viscoelastic analogy,** *EERC 75-40,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1975, 30. (NTIS Accession No. PB 252 173)

An alternative representation of the elastic-viscoelastic correspondence principle for solids similarly viscoelastic in bulk and shear, and subjected to steady-state harmonic excitation, is derived. This form of the elastic-viscoelastic analogy is particularly useful when the elastic solution is not available in closed form, but is only known numerically, say in tabular form. The analyticity property of the frequency response function is utilized to formulate a Dirichlet problem in the lower half of the complex plane with the elastic solution on the real line as the boundary data. An infinite integral representation for the viscoelastic frequency response function is then obtained, where the elastic frequency response and viscoelastic properties enter in the integrand. This integral may be evaluated numerically using a suitable quadrature formula, and the known discrete numerical values of the elastic frequency response function, to generate an approximation to the viscoelastic frequency response function. The computation can be monotonically refined by the inclusion of more elastic data points. A simple example is presented to illustrate an application of this alternative formulation.

● **6.12-114** Mondkar, D. P. and Powell, G. H., **ANSR-I: General purpose program for analysis of nonlinear structural response,** *EERC 75-37,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1975, 145. (NTIS Accession No. PB 252 386)

ANSR is a general purpose computer program for static and dynamic analysis of nonlinear structures. This report documents the features and organization of the current version of the program. The theoretical formulations and solution schemes used in the program are described, and details are given about the structure and organization of the auxiliary program for adding new finite elements to the program. Several examples are presented to illustrate the scope of ANSR. The user's manual for the program is described.

● **6.12-115** Goodno, B. J., **Dynamic analysis of suspended-floor highrise buildings using super-elements,** *13,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Jan. 1975, 252.

The earthquake integrity of a new concept in multistory building construction utilizing an unconventional structural system is investigated. The primary structural elements of the system are two reinforced concrete core towers from which are suspended steel frame floors with concrete floor slabs. Steel hanger straps draped over the cores constitute the floor suspension system and allow the floors to hang down about the cores. A gap of about three inches is left between floor, and core and one-inch-square steel "bumper bars" welded to the floor girders at core corners bridge this gap to provide for transmission of lateral forces due to wind and moderate earthquakes. However, these small replaceable bars are intended to fracture in a strong earthquake, thereby permitting the floors to sway freely and dissipate energy.

A three-dimensional analytical model is presented for the linear dynamic analysis of such a suspended-floor highrise building. Computer programs written for the study are described in detail, and several sample runs are presented to demonstrate the validity of the analytical model for the building. The computer-generated response of the system to wind gust and earthquake loading conditions also is presented. The response of two existing suspended-floor highrise structures were examined under ambient and forced-vibration conditions. The IED Building in Mountain View, California, and the Sherman Building in San Jose, California, were the structures tested. A comparison of measured and calculated natural frequencies for each of these structures demonstrates the validity of the core tower and building analytical models presented in this report.

6.12-116 Tomii, M. and Yamakawa, T., **Relations between the nodal external forces and the nodal displacements on the boundary frames of rectangular elastic framed shear walls—Part II: Relations between the nodal displacements and the representative components of their fundamental components,** *Transactions of the Architectural Institute of Japan, 238,* Dec. 1975, 37–46.

This paper continues the study of the relations between the nodal external forces and the nodal displacements on the boundary frames of rectangular elastic framed shear walls. Properties of the transformation matrices of the components of the nodal external forces and the nodal displacements are given.

● **6.12-117** Wilson, E. L., Hollings, J. P. and Dovey, H. H., **Three dimensional analysis of building systems (extended version),** *EERC 75-13,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1975, 126. (NTIS Accession No. PB 243 989)

A procedure and a computer program are developed for the linear structural analysis of frame and shear wall buildings subjected to both static and earthquake loadings.

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The building is idealized by a system of independent frame and shear wall elements interconnected by floor diaphragms which are rigid in their own plane. Within each column, bending, axial and shearing deformations are included. Beams and girders may be nonprismatic, and bending and shearing deformations are included. Also shear panels can be considered. Finite column and beam widths are included in the formulation. Nonsymmetric, nonrectangular buildings which have frames and shear walls located arbitrarily in plan can be considered. Three independent vertical and two lateral static loading conditions are possible. The static loads may be combined with a lateral earthquake input which is specified as a time-dependent ground acceleration or as an acceleration spectrum response. Three-dimensional mode shapes and frequencies are evaluated.

Frame and shear walls are considered as substructures in the basic formulation; therefore, for many structures input data preparation can be minimized and a significant reduction in computational effort can result in this approach.

This is an extension of TABS to enable three-dimensional frames to be input in which full compatibility exists.

6.12-118 Sato, T., **On the analysis of frame with seismic-resistant wall by the shear flow equation** (in Japanese), *Transactions of the Architectural Institute of Japan, 233*, July 1975, 101-108.

This paper presents a method for analyzing a frame having seismic-resistant walls, which is subjected to a lateral force. The shearing rigidity of a frame without a wall is substituted for a thin wall equal to its rigidity, and the bending rigidity of a seismic-resistant wall is substituted to areas at either side of the wall. Then, the frame is substituted for a plane field with various thicknesses and various areas of stringers. A shear flow equation is introduced by the continuous condition deduced by the strain energy of the frame and by the equilibrium of the shear flow in the total field. The shear flow of each field and the deflection of each story are solved by this equation. From these results, shear forces to which each member is subjected are calculated. A bilinear solution can be derived by making a partial revision of the shear flow equation. This method has been compared with photoelastic experiments and other methods, and good agreement has been obtained.

With the method presented, arbitrary frames with seismic-resistant walls having random variations of story heights, thicknesses and wall arrangements can be solved. The method provides for appropriate distribution of frame shear stress.

● 6.12-119 McNiven, H. D. and Matzen, V. C., **A mathematical model of a single story earthquake resistant steel frame**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 165, 6. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper, both model tests and mathematical analysis are used to study the response of structures to earthquakes. A one-story steel frame is studied, and its behavior is modeled by means of a single differential equation. The equation accommodates linear viscous damping and energy absorption due to hysteretic material behavior according to the Ramberg-Osgood formulation. Viscous damping introduces one physical parameter to the equation, and the Ramberg-Osgood terms introduce three. This differential equation, along with its four parameters, represents the model of the single-story steel frame.

The purpose of the study is to estimate the set of parameters that will give the closest correspondence between the response of the mathematical model and the building it is modelling and thus find the model that best represents the experimental frame. In addition, by examining the model, insight into the energy absorbing characteristics of the steel frame may be gained. For example, it is possible to find whether the parameters found from this dynamic test are different from those found from quasi-static tests.

6.13 Nondeterministic Methods of Dynamic Analysis

● 6.13-1 Pereira, Jervis, **Probability methods in seismic engineering** (Métodos probabilísticos em engenharia sísmica, in Portuguese), *Memoria No. 442*, Lab. Nacional de Engenharia Civil, Lisbon, 1974, 199.

By making use of concepts of the theory of probability, the definition of probabilistic models for seismic loading is studied, with special emphasis on the stationary model. Starting from the properties of the model, the paper presents some important statistics of the response of a linear oscillator, with one degree-of-freedom, namely the statistics of the maximum values within an interval of time. These results allow easy generalization to a linear oscillator with N degrees-of-freedom and the working out of a program known as "Statismax." Finally, by using a branch of the theory of Markov processes, that of the diffusion processes, the response of a nonlinear oscillator to white noise loading is determined, and the results obtained are compared with those presented by other authors.

● 6.13-2 Schiff, A. J., Newsom, D. E. and Fink, R. K., **Lifeline simulation methods of modeling local seismic environment and equipment damage**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 446-455.

A simulation method is presented for evaluation of the response of an electric utility system to major earthquakes. Digital Monte Carlo methods are used in the simulation. The system is viewed as a network, and system reliability is evaluated relative to a number of specified, surrounding random earthquake sources. The methods used to determine the local seismic environment are described; this information is then used to estimate equipment response and damage.

6.13-3 Wittig, L. E. and Sinha, A. K., **Simulation of multicorrelated random processes using the FFT algorithm,** *The Journal of the Acoustical Society of America,* **58**, *3*, Sept. 1975, 630-634.

A technique for the digital simulation of multicorrelated Gaussian random processes is described. This technique is based upon generating discrete frequency functions which correspond to the Fourier transform of the desired random processes, and then using the fast Fourier transform (FFT) algorithm to obtain the actual random processes. The main advantage of this method of simulation over other methods is computation time; it appears to be more than an order of magnitude faster than present methods of simulation. One of the main uses of multicorrelated simulated random processes is in solving nonlinear random vibration problems by numerical integration of the governing differential equations. The response of a nonlinear string to a distributed noise input is presented as an example.

● 6.13-4 Chen, P. C., **Floor response spectra of buildings with uncertain structural properties,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 519-528.

The floor response spectra of buildings with uncertain structural properties are calculated by using a method similar to one previously proposed by Chen and Soroka. However, in this investigation, a different approach is used in determining the probabilistic dynamic response from the deterministic dynamic response. The probabilistic floor response spectra are compared with those obtained deterministically and are shown to provide a more reliable method in determining seismic forces for equipment design.

● 6.13-5 Wen, Y.-K., **Approximate method for nonlinear random vibration,** *Journal of the Engineering Mechanics Division, ASCE,* **101**, *EM4,* Proc. Paper 11500, Aug. 1975, 389-401.

An approximate method for nonstationary solution of nonlinear systems under random excitation is presented. The nonlinearities in the restoring force are of the polynomial type. The excitation is either shot noise or filtered shot noise. The solution is based on a Markov-vector approach. The unsteady Fokker-Planck-Kolmogorov equation for the nonlinear system is solved approximately by a Galerkin method where a time-dependent Hermite-series expansion is used and the equation is reduced to a system of first-order ordinary differential equations. The method is illustrated by numerical examples on a damped Duffing oscillator and a Ramberg-Osgood yielding system. Comparison of results obtained herein with exact stationary solution and Monte Carlo results indicates that the proposed method is powerful and efficient for study of nonlinear systems.

● 6.13-6 Yang, J.-N., **Approximation to first passage probability,** *Journal of the Engineering Mechanics Division, ASCE,* **101**, *EM4,* Proc. Paper 11502, Aug. 1975, 361-372.

In the theory of random vibration, a problem of considerable practical importance is to determine the probability, called first passage or first excursion probability, that the structural response will pass out of safety bounds or thresholds for the first time within a specified time interval. Within the framework of the point process approach, a recurrence solution for approximating the first passage probability of a Gaussian random process, stationary or nonstationary, is suggested herein. Numerical results of the present approximation are displayed, along with the results of other approximations. It is shown that the accuracy of the present approximation is satisfactory compared with the results of numerical simulation.

6.13-7 Lowrey, M. J., **Use of correlation techniques in vibration studies of plate systems,** *Experimental Mechanics,* **15**, *12,* Dec. 1975, 476-481.

This paper describes the application of pseudo-random test signals and cross-correlation analysis to the determination of the dynamic response characteristics of plate systems. The statistical nature of the technique allows such information to be obtained even in the presence of considerable background noise. The method is demonstrated by a pilot study performed on a rectangular isotropic plate and by additional tests on plates with longitudinal rib stiffeners. In all cases the results compare favorably with those given by an alternative (but more tedious) experimental procedure and, to a lesser extent, with theoretical solutions.

● 6.13-8 Yang, J.-N., **Diffusion of probability mass and first passage probability,** *Journal of the Engineering Mechanics Division, ASCE,* **101**, *EM5,* Proc. Paper 11654, Oct. 1975, 639-647.

The probability that the structural response will pass out of the safety bounds for the first time within a specified time interval is called first passage or first excursion probability. The Fokker-Planck equation for the transi-

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tional probability of a Markov process, which is a continuity equation for the flow of probability mass, is studied in relation to the first passage probability. The thresholds or barriers considered are that both the displacement response, X(t), and the velocity response, Y(t), should be less than some specified values, i.e., the safe domain is a rectangle in the phase plane. An upper bound to the first passage probability is obtained by computing the total stationary flow of probability mass across the thresholds into the unsafe domain. An approximation to the first passage probability is derived based on the assumption that the probability flux across the thresholds into the unsafe domain is proportional to the total probability mass remaining in the safe domain, which is a reasonable assumption for high-level thresholds.

● 6.13-9 Corotis, R. B. and Vanmarcke, E. H., **Time-dependent spectral content of system response**, *Journal of the Engineering Mechanics Division, ASCE*, **101**, *EM5*, Proc. Paper 11648, Oct. 1975, 623–637.

Random vibration analysis provides a meaningful way to assess the ability of a structure to withstand seismic and wind forces. In the former case the nonstationarity of the mean square value and relative frequency content is important. The concept of a time-dependent frequency domain description of a random process is applied to a linear one-degree-of-freedom system suddenly exposed to a zero-mean steady wide-band random excitation. The evolving bandwidth of the oscillator response can be measured by a shape function in terms of the first few spectral moments of the response time-dependent spectral density function. The shape depends on the oscillator damping and the number of cycles of response. The result can be used to estimate the equivalent viscous damping from recorded structural response to earthquake or wind excitation. Record length and oscillator period and damping affect the reliability of the damping estimate.

● 6.13-10 Kayser, K. W. and Bogdanoff, J. L., **A new method for predicting response in complex linear systems**, *Journal of Sound and Vibration*, 38, *3*, Feb. 8, 1975, 373–385.

A new method is presented for response estimation in complex lumped parameter linear systems under random or deterministic steady state excitation. The method uses relaxation procedures with a suitable error function to find the estimated response; natural frequencies and normal modes are not computed. Since accuracy of the estimates may be exchanged for low computation cost, the method appears suitable for design purposes.

Three examples are considered having 45, 52, and 98 degrees-of-freedom with excitation in relatively high frequency bands.

● 6.13-11 Prasthofer, P. H. and Beadle, C. W., **Dynamic response of structures with statistical uncertainties in their stiffnesses**, *Journal of Sound and Vibration*, **42**, *4*, Oct. 22, 1975, 477–493.

A technique is derived to compute the instantaneous transient response statistics of an undamped linear *N*-degree-of-freedom structure subjected to arbitrary but deterministic forcing functions, when random uncertainties are introduced into the stiffness matrix. The uncertainties are modeled as perturbations with a Gaussian distribution. For the case of an impulsive driving function, simple bounds are derived showing the growth with time of the response uncertainty as a function of the model uncertainty.

● 6.13-12 Roberts, J. W. and Robson, J. D., **The simulation of random vibration response by discrete frequency testing**, *Journal of Sound and Vibration*, **42**, *4*, Oct. 22, 1975, 429–436.

The paper presents the theoretical basis for an analog method whereby the random response of a structure may be inferred from measurements of its harmonic response when the excitations are replaced by discrete frequency forces or imposed motions. In the elementary case of a single random input, the method takes a particularly simple form. In the general multi-input case, it is shown that the method may be used directly only when all the inputs are fully coherent. Otherwise a superposition technique involving multiple applications of sets of harmonic excitations is required. It is considered that the method may be of practical use as a tool in vibration testing and that, in addition, the underlying analysis contains results of considerable interest on the structure of multidimensional stationary random processes.

● 6.13-13 Orris, R. M. and Petyt, M., **Random response of periodic structures by a finite element technique**, *Journal of Sound and Vibration*, **43**, *1*, Nov. 8, 1975, 1–8.

A finite element method is presented for analyzing the response of periodic structures to convected random pressure fields. It is shown that the problem reduces to one of finding the response of a single periodic section to a harmonic pressure wave. In this case the inertia, stiffness and damping matrices become functions of the phase difference between the pressures at corresponding points in adjacent sections. The method is applied to a skin-rib type structure.

● 6.13-14 Ohta, M. *et al.*, **A unified study on the output probability distribtuion of arbitrary linear vibratory systems with arbitrary random excitation**, *Journal of Sound and Vibration*, 43, *4*, Dec. 22, 1975, 693–711.

New theoretical expressions of probability density and cumulative distribution functions for the output response

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are exactly derived. The expressions are derived without any simplification of the problem and any approximation of analysis in the case when a general random signal with arbitrary probability distribution and correlation functions is passed through an arbitrary linear vibratory system with finite order. The result is given as an explicit solution of expansion series in a functional form of input statistics and vibratory system paramters, and not given as a mere numerical solution by use of a recurrence algorithm. An effect of random input and system characteristics is concretely reflected in the expansion coefficients. The experimental results obtained by digital simulation are in good agreement with the theory.

● 6.13-15 O'Rourke, M. J., Parmelee, R. A. and Corotis, R. B., **Response of structures to random wind forces,** *Journal of the Structural Division, ASCE,* **101**, *ST12*, Proc. Paper 11786, Dec. 1975, 2557-2571.

The effect of wind forces is of primary importance in the design of tall buildings. Since wind forces are random variables, it is necessary to approach the problem from a statistical viewpoint. This paper presents a method for making an analysis of the response of a building subjected to a wind loading. The forcing function is assumed to be an independent stationary stochastic process, and the standard deviations of the floor displacements are the output of the analysis. Also presented is a study of the effect of neglecting inertia and damping terms associated with flexural motions of the floor analysis. Finally, an approximate method for determining the standard deviations of the rigid body floor displacements is presented which yields results that are within 10% of the exact values.

● 6.13-16 Iyengar, R. N. and Jagadish, K. S., **Probability of failure of structures under earthquake excitations,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 253-258.

This paper presents a probabilistic response analysis of a linear single-degree-of-freedom system under a nonstationary Gaussian random process excitation. The excitation is a band limited white noise multiplied by a deterministic time function, which simulates strong-motion epicentral earthquakes reasonably well. The response autocorrelation is found, followed by a determination of the average number of level crossings. This information is used to get an approximation to the highest peak distribution. Numerical results are presented for a ten-second earthquake. Some results obtained by a sample analysis also are given.

● 6.13-17 Singh, M. P. and Chu, S. L., **An alternate approach to seismic analysis of structures,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 237-244.

Response spectra are most commonly used in characterizing earthquake motions for structural design. As Newmark and others have suggested, such spectra can be obtained easily, and they can be used with a great deal of confidence. However, this method of characterization has its own limitations since not every problem in seismic analysis can be effectively treated using such a spectrum. Therefore, either an alternate model for characterizing earthquake ground motions, or a method by which a spectrum can be used more effectively, is required. Since earthquake motions are generated through numerous random phenomena and since they have the appearance of random time functions, random modeling of earthquakes is probably more desirable.

A method is proposed in which data available from a response spectrum can be used for random modeling of earthquakes. Seismic motions represented by a spectrum are assumed to be stochastically stationary, and the concept of a spectrum-consistent power spectral density function (PSDF) is developed. How this PSDF is obtained and later used in seismic analysis is described. It is shown that the proposed method can be used effectively to obtain reliable member response, floor spectra, etc., of a building. Other conventional methods of analysis, such as the response spectrum and the time history methods, also are examined vis-a-vis the proposed method. However, it is felt that for complex structural systems these methods should be used with restraint.

The concept of stochastic modeling is extended further to develop rational methods whereby evaluation of mode interaction effect of closely spaced modes on member response and generation of floor spectra can be accomplished using a response spectrum directly. These methods give accurate results and require insignificant computational time when compared with methods such as time history analysis.

● 6.13-18 Roberts, J. B., **Probability of first-passage failure for nonstationary random vibration,** *Journal of Applied Mechanics,* **42, Series E,** *3,* Sept. 1975, 716-720.

The problem of calculating the probability of first-passage failure is considered for systems responding to a short pulse of nonstationary random excitation. It is shown, by an analysis based on the "in and exclusion" series, that under certain conditions the probability of first-passage failure tends to the probability calculated by assuming Poisson-distributed barrier crossings as the barrier height tends to infinity. The first three terms in the series solution provide bounds to the probability of first-passage failure, which converge when the barrier height is large. Methods of estimating the first-passage failure probability from these terms are presented, which are useful even when the series is divergent. The theory is illustrated by numerical results relating to a linear oscillator excited by modulated white noise.

● 6.13-19 Moan, T., Haver, S. and Vinje, T., **Stochastic dynamic response analysis of offshore platforms, with particular reference to gravity-type platforms,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2407, May 1975, 707–720.

A computerized method for stochastic dynamic response analyses of framed structures with a caisson-type foundation has been developed. The dynamic response is determined by a finite element idealization of the structure. A lumped-mass formulation is used. The effect of the soil is taken into account by a linear elastic halfspace model, which provides equivalent spring and dashpot constants. Hysteretic damping in the soil also is included. The hydrodynamic loading (excitation forces), mass and damping on the superstructure is evaluated according to the Morison equation. However, the inertia forces are evaluated in separate analyses with due consideration of diffraction effects. The hydrodynamics of the caisson are based on available experimental results. The equations of motion are solved using the normal mode superposition approach. The response quantities are then transformed into long-term statistics of displacements, forces and moments using appropriate weather data. Numerical results are presented for an example platform. A parameter study is carried out to study the effect of the shear modulus of the soil on the response.

● 6.13-20 Penzien, J., **Seismic analysis of platform structure-foundation systems,** *Proceedings, 1975 Offshore Technology Conference,* Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2352, May 1975, 153–164.

Dynamic analysis procedures, both deterministic and stochastic, are described for predicting the seismic response of platform structure-foundation systems. Each system is modeled mathematically by a combination of linear and nonlinear elements representing both the tower structure and the pile foundation. Hydrodynamic drag and inertia forces are included, fluid-tower interaction is considered and soil-pile-tower interaction is treated using the theory of the elastic halfspace. Horizontal earthquake excitation is prescribed, either at the bottom level of the piles or at the free-surface level of the soil. This excitation is considered in the form of acceleration time history, response spectra, or as a stochastic process. Numerical results of a stochastic analysis are presented and interpreted in terms of present design requirements.

● 6.13-21 Müller, F. P. and Henseleit, O., **Elastic-plastic systems excited by non-stationary random vibrations,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 60, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

Time-history analysis normally gives results that are not statistically significant. Modal-response analysis avoids this disadvantage but the response of light equipment cannot be analyzed using the method. For this reason, a method has been developed to obtain the response of systems with many degrees-of-freedom, excited by nonstationary random noise. The description of the results as evolutionary spectra makes it possible to analyze light equipment. In the case of elastic-plastic behavior, the structural safety of buildings can be estimated by means of the total plastic strain.

6.13-22 Kobori, T., Minai, R. and Asano, K., **On stationary random response of the multi-mass building structure in the hysteretic plastic deformation region** (in Japanese), *Transactions of the Architectural Institute of Japan, 231,* May 1975, 21–29.

In a previous paper, response characteristics of a hysteretic single-degree-of-freedom system to white and nonwhite inputs were examined by a new analytical technique based on the Fokker-Planck equation and the characteristic function. Such important parameters, from an aseismic design point of view, as the rigidity ratio of hysteretic characteristics, viscous damping independently given with hysteretic damping to the system and the shape of the nonwhite noise spectrum were considered.

In this paper, a method to estimate random response of the multidegree-of-freedom system is developed by extending and making use of this new analytical technique. As a brief example of this method, two-degree-of-freedom systems are analyzed to obtain general random response characteristics of the hysteretic system for the following parameters: (1) the level of white noise inputs power spectral density, (2) the ratio of the masses of the second and first stories and (3) the ratio of the rigidities of the second and the first stories.

6.13-23 Tsuboi, Y., **Parametric study of elastic buckling of shells with reference to Gaussian curvature–Part I: Buckling from membrane stress state** (in Japanese with English summary), *Transactions of the Architectural Institute of Japan, 230,* Apr. 1975, 37–42.

In this paper, the variation of the critical load in the elastic buckling of shells is investigated in terms of Gaussian curvature as a parameter. Using a Cartesian coordinate in the formulation, it is shown that the shallow shell theory of Vlasov, which was refined by the author in the bending moment-change of curvature relation, can be successfully applied to the buckling problem of nonshallow shells. The buckling load of shells having middle surfaces of various shapes is obtained in terms of the parametric coefficient of

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Gaussian curvature. A method of obtaining the buckling load of shells of arbitrary Gaussian curvature is presented in a compact formulation. It is shown that the classical buckling loads for spherical and cylindrical shells are the same as those from the present method.

● 6.13-24 Vanmarcke, E. H., **On the distribution of the first-passage time for normal stationary random processes,** *Journal of Applied Mechanics*, **42**, **Series E**, *1*, Mar. 1975, 215-220.

New approximate distributions of first-passage time for normal stationary random processes are derived. One estimate is particularly suitable for use in dealing with the stationary response of linear vibratory systems. A major advantage of the proposed solution is that it can easily be extended to obtain first-passage estimates for nonstationary random processes whose frequency content can be described in terms of a time-dependent or evolutionary spectral density function. In all cases, the method presented was found to be in good agreement with simulation results, to be relatively simple to use, and to lead to predictions which are at least as good as those obtained by other, much less tractable, analytical methods.

6.13-25 Berge, B. and Penzien, J., **Three-dimensional stochastic response of offshore towers to wave action,** *SESM 75-10*, Div. of Structural Engineering and Structural Mechanics, Univ. of California, Berkeley, Oct. 1975, 148.

A theory is developed to calculate the dynamic response of offshore towers to random wave forces. Vibrations are considered simultaneously for translations in the orthogonal horizontal directions and for rotations about a vertical axis. The idealized structure for the dynamic analysis has its masses lumped at discrete horizontal levels.

The ocean waves are considered to be a zero mean stationary ergodic Gaussian random process described by the directional wave spectrum, which specifies the distribution of wave energy with respect to frequency and direction. This is an approximation to reality since such a wave spectrum is based upon the superposition of "linear" waves. Using linear wave theory and the Morison wave force equation, modified to take structural motion into account, spectral densities for the wave forces are obtained. The wave forces are applied to the structure at the submerged levels where the tower legs are located, thus the method takes into account the fact that wave forces are not in phase over the horizontal extension of the structure. Drag forces on the structure are linearized. The equations of motions are solved in the frequency domain using the normal mode superposition. Modal damping coefficients are uncoupled through an optimizing procedure. Spectral densities are obtained for the response in the various modes in normal coordinates, and mean products of the responses are obtained by integrating the spectral densities numerically over the frequency range. These response quantities are then transformed into statistics of displacements, rotations, shear forces and bending and twisting moments. Tower leg displacements are determined by combining translations and rotations of the structure.

Two computer programs, one for towers symmetric about two vertical planes and one for towers symmetric about one vertical plane, have been written to determine the above-mentioned quantities. The computer solution for a tower that is symmetric about a vertical plane which has its masses lumped at 7 horizontal levels (21 degrees-of-freedom), requires approximately 1 minute central processor time on the CDC 6400 computer when 11 frequencies are used for the numerical integration of the spectral density functions.

Numerical results for seven deep water towers having heights of 475, 675, 875 and 1075 ft are presented. These results include standard deviations and mean peak values for displacements, rotations, shear forces and twisting and bending moments. They show that the directional spread of the waves normally has little effect on the rotational response, and that the effect of the rotational response on the overall structural response is small.

● 6.13-26 Dalal, J. S., **Probabilistic seismic exposure and structural risk evaluation,** *15*, The John A. Blume Earthquake Engineering Center, Stanford Univ., Jan. 1975, 208.

A seismic design methodology incorporating earthquake phenomenology, structural behavior analysis and decisionmaking is proposed, and its application is demonstrated. Emphasis is placed on probabilistic evaluation of seismic exposure in terms of statistical predictions of pseudo-absolute acceleration response spectra. Structural response and potential damage and loss under seismic exposure are discussed, and incorporation of these structural behavioral aspects in the design process is demonstrated.

● 6.13-27 Bosshard, W., **On stochastic load combination,** *16*, The John A. Blume Earthquake Engineering Center, Stanford Univ., July 1975, 67.

The importance of studying stochastic load combination problems for structural elements is discussed. Previous work in the field is reviewed. A case is made for second-moment analysis of safety using results from parametric stochastic load models and first-order second moment procedures applied to all other random variables in the interaction equation for a specific failure mode of a structural element.

A classification of stochastic load combination problems according to the formal structures of load terms is proposed. The resulting safety index (the logarithmic

Rosenblueth β) is understood as an approximately ordinal scale of measurement for the inaccessible probability of failure. The question of the size of ordinal classes (how large is the class of problems whose β can be compared to each other) is asked. The technical aspects of stochastic load combination are examined.

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7. Earthquake-Resistant Design and Construction and Hazard Reduction

7.1 General

● 7.1-1 Zsutty, T., **Some problems and decisions relative to the response spectrum method of seismic design,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 87–93.

A description is given of some of the problems and related decision alternatives involved in the use of the response spectrum method as a practical design procedure. No solutions, levels, or procedures are recommended for the problems or decisions related to each basic step; the purpose is to emphasize that the response spectrum method of design is a series system and that a decision at any step can have a definite influence on the eventual achievement or nonachievement of the design objectives.

● 7.1-2 Cherry, J. T., Halda, E. J. and Hamilton, K. G., **A deterministic approach to the prediction of free field ground motion and response spectra from stick-slip earthquakes,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 1–9.

Theoretical and experimental results from computational physics and nonlinear rock mechanics have been merged in order to obtain a deterministic model of a stick-slip earthquake. The model has been exercised to uncover the dependence of peak ground motion and response spectra on fault length, rupture velocity and dynamic stress drop during rupture. A particular method for generating a design spectrum has been tested against results from the model. Utilization of this deterministic technique seems especially appropriate when design information is required at sites located near the epicenter.

● 7.1-3 Berg, G. V., **Design procedures, structural dynamics, and the behavior of structures in earthquakes,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 70–76.

What engineers east of the Rockies should do, if anything, toward incorporating earthquake resistance into the design of structures is examined. First, the basic provisions of the Uniform Building Code are discussed; then, several rules of thumb that the engineer might use to limit earthquake damage are presented. The author's own design philosophy is presented at the end of the paper.

7.1-4 Fedorov, E. I., **Determination of safety factors on the basis of economic considerations** (K voprosu opredeleniia kharakteristik nadezhnosti iz ekonomicheskikh soobrazhenii, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1,* 1974, 4–5.

A method for finding optimal safety factors for structures whose failure might have various consequences is presented. The significance of the transitional probability matrix representing the relationship between the type of failure and the cost of repair is explained.

7.1-5 Karpenko, N. I. and Gurevich, A. L., **On design of reinforced concrete beam and wall taking account of cracks** (O raschete zhelezobetonnykh balok-stenok s uchetom treschin, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1,* 1974, 22–24.

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A computerized design method of reinforced concrete beam-and-wall is considered which takes into account crack formation and development under loads. The deformation model considered takes into account the angle between the crack and reinforcement, the real energy absorption of the reinforcement inside the cracks and the concrete between them. A comparison is made between the results and experimental data.

7.1-6 Rzhanitzin, A. R. and Zakharov, V. M., **Design of inelastic rod assemblies with inelastic shear ties** (Raschet sostavnykh sterzhnei iz neuprugogo materiala s neuprugimi svyazami sdviga, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1*, 1974, 16–18.

A system of equations applicable to an arbitrary number of rods and with various energy absorption patterns in the ties is presented. Lateral ties are assumed to be perfectly rigid. An example using the step-by-step method is given, and a comparison is made with the elastic phase method.

● 7.1-7 Donovan, N. C., Valera, J. E. and Beresford, P. J., **Statistical uncertainty of design based on smoothed response spectra**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 53–59.

Recent emphasis on numerical analyses has led to the concept of a single artificial acceleration history which has a computed response spectrum closely matching that of a specified design spectrum. It has been asserted that design based on use of this single acceleration history will be reliably conservative. The validity of this conclusion is tested in this paper by the use of a simple structural model subjected to a set of five acceleration histories whose response spectra at a specified damping value closely match the current Nuclear Regulatory Commission requirements. The authors conclude that use of an acceleration history whose response spectrum matches a prescribed spectrum does not assure a conservative design.

7.1-8 Green, M. F. and Stafford-Smith, B., **Probability theory as a basis for building design**, *Building Science*, **10**, 3, Oct. 1975, 177–183.

This paper identifies the significant role that statistics and probability theory can play in the design of many building subsystems. It shows possible improvements in the current methods of design of these individual subsystems as well as the benefits to the total building design if the probabilistic implications are acknowledged.

7.1-9 Manapov, A. Z. and Pikulev, N. A., **Optimal parameters of vibration damper system for harmonic excitation with unstable frequency** (Optimalnye parametry gruppy vibrogasitelei pri nestabilnoi chastote garmonicheskogo vozdeistviya, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1*, 1975, 33–35.

A system of vibration dampers with varying frequency distribution curves relative to the resonant frequency of the primary system is considered. The optimal specifications and frequency band widths insuring the maximal value for the minimum dynamic stiffness of the system are calculated. The technique is explained and numerical examples given. The results are applicable to vibration damper systems for industrial buildings subjected to horizontal loadings from machinery working with varying speeds.

7.1-10 Koshkin, L. V. and Nudelman, Ya. L., **On the problem of controlling the natural frequencies of elastic systems** (K voprosu ob upravlenii sobstvennymi chastotami uprugikh sistem, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1*, 1975, 35–39.

Elastic systems with stiffness and mass distribution dependent on a finite number of parameters are considered. The partial derivatives of natural frequencies with respect to those parameters are calculated. The results may be used to modify natural frequencies and to optimize dynamic behavior of structures. A class of structures is found where the fundamental frequency reaction surface is unimodal, and thus the search for optimal structural design is substantially simplified.

7.1-11 Shestoperov, G. S., **On the problem of generalizing the standard formula for calculating seismic loads** (K voprosu obobshcheniya normativnoi formuly dlya opredeleniya seismicheskoi nagruzki, in Russian), *Sbornik nauchnykh trudov VNII transportnogo stroitelstva, 67*, 1975, 22–30.

Generalized formulas for the calculation of seismic loads of a system in transient motion with varying vibration amplitudes are obtained using methods of operational and matrix calculus.

7.1-12 Goldenblat, I. V. and Poliakov, S. V., **The problem of engineering risk in earthquake-resistant construction** (Problema "inzhenernogo riska" v seismostoikom stroitelstve, in Russian), *Byulleten stroitelnoi tekhniki, 7*, 1975, 22–23.

The problem of engineering risk in earthquake-resistant construction has been attracting more attention recently both in the U.S.S.R. and abroad. Sociological and economic aspects of the problem are of great importance, and in some cases, factors such as reducing construction time and costs are decisive. At the same time, decisions during the design process are made on the basis of data which are both incomplete and unreliable. Problems of efficiency and engineering risk in earthquake-resistant construction must be solved systematically with all aspects of

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the problem (seismological, sociological, economic and engineering) taken into account. The starting point in this respect should be the statistical analysis of earthquake effects and a combined statistical and economic study of the relationship between expected building damage and the initial cost of earthquake-resistant design features. A brief analysis of various structures is given.

● 7.1-13 Olhoff, N., **Optimal design of vibrating rectangular plates,** *International Journal of Solids and Structures,* **10,** *1,* Jan. 1974, 93–109.

The thickness function of a simply supported rectangular plate is determined such that the fundamental natural frequency of transverse vibrations attains an optimum value. The volume of the solid plate, its size and data pertaining to its material properties are assumed to be given.

The problem consists of determining the deflection function corresponding to the optimal plate thickness function from a nonlinear, fourth-order partial differential eigenvalue problem, derived by variational analysis.

Second- and higher-order normal derivatives of the deflection function are singular along the boundary of the domain. This behavior is investigated analytically, and taken into account in a finite difference formulation of the problem, which is solved numerically by successive iterations.

7.1-14 Teal, E. J., **Seismic design practice for steel buildings,** *Engineering Journal, AISC,* **12,** *4,* 1975, 101–151.

To properly interpret seismic codes and their revisions, it is becoming increasingly important that the design engineer have an understanding of the basic theory behind seismic code provisions. This paper provides a brief treatment of the subject of seismic theory and design, particularly as it applies to structural steel. Much of the theory is condensed into simple terms more readily applied to the typical problems faced by busy design engineers. Specific seismic code provisions are discussed to aid in their interpretation.

The author has specifically addressed the situation of engineers designing for the earthquake problems and building codes of the state of California. No attempt has been made to cover conditions not applicable to California. However, it is hoped that the paper will prove helpful to any engineer involved in the seismic design of steel buildings.

● 7.1-15 Munjal, M. L., **A rational synthesis of vibration isolators,** *Journal of Sound and Vibration,* **39,** *2,* Mar. 22, 1975, 247–263.

The paper deals with a rational approach to the development of general design criteria for nondissipative vibration isolation systems. The study covers straight-through spring-mass systems as well as branched ones with dynamic absorbers. Various design options, such as the addition of another spring-mass pair, replacement of an existing system by one with more spring-mass pairs for the same space and material requirements, provision of one or more dynamic absorbers for the desired frequency range, etc., are investigated quantitatively by means of an algebraic algorithm. The algorithm enables one to write down at once the velocity ratio and, hence, transmissibility of a linear dynamic system in terms of the constituent parameters.

● 7.1-16 Cempel, Cz., **Receptance model of the multi-unit vibration impact neutralizer–MUVIN,** *Journal of Sound and Vibration,* **40,** *2,* May 22, 1975, 249–266.

In this paper a receptance model of the multi-unit vibration impact neutralizer (MUVIN) is formulated. This approach provides the possibility of dynamic analysis and synthesis of the interaction of any mechanical system with the MUVIN system. It is proved, by both theoretical and experimental results, that the MUVIN system may be used for the neutralization of resonant structural vibrations.

● 7.1-17 Gorzynski, J. W. and Thornton, W. A., **Variable energy ratio method for structural design,** *Journal of the Structural Division,* ASCE, **101,** *ST4,* Proc. Paper 11266, Apr. 1975, 975–990. (For an additional source, see Abstract No. 7.1-12, *AJEE,* Vol. 4.)

Minimum weight design of trusses and frames using a method involving the maximization of the member energy ratios is treated. The energy ratio of a member is the ratio of the strain energy stored in a member when the structure is subjected to a particular load condition to that which could be stored in the member. Presented are a theorem that justifies the maximization of the energy ratios to minimize weight as well as heuristic algorithms to effect this maximization. These algorithms have been tested using a number of truss and frame structures subjected to multiple static loads and to simple harmonic dynamic loads, considering stress, local buckling, and displacement constraints. The results indicate that the method is very effective in obtaining minimum weight designs of trusses and frames.

● 7.1-18 Whitman, R. V. *et al.,* **Seismic design decision analysis,** *Journal of the Structural Division, ASCE,* **101,** *ST5,* Proc. Paper 11309, May 1975, 1067–1084.

Seismic design decision analysis is a procedure for organizing into a useful format the information required to arrive at a balance between the cost of designing to give earthquake resistance and the risk of damage and loss of

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lives in future earthquakes. The likelihood of ground shaking of various intensities is evaluated using Cornell's seismic risk model. Building performance is expressed by damage probability matrices, empirical evidence from past earthquakes—especially the San Fernando, California, earthquake—plus theoretical analysis and subjective judgment are used to develop such matrices. The cost of increased seismic resistance is determined by designing a series of typical buildings. All this information is then combined to provide estimates of costs and losses. The apparent conclusion is that design against earthquakes is justified only if one either makes a very conservative interpretation of the seismic risk or places a very high value on saving lives.

● 7.1-19 Yang, J.-N., **Application of optimal control theory to civil engineering structures,** *Journal of the Engineering Mechanics Division, ASCE,* **101**, *EM6*, Proc. Paper 11812, Dec. 1975, 819-838.

Modern control theory has been successfully applied to control the motions of aerospace vehicles. An exploratory study is made herein to investigate the feasibility of applying such a theory to control the vibration of civil engineering structures under random loadings. It is assumed that random excitations to structures, such as wind loads and earthquakes, can be modeled by passing either a stationary Gaussian white noise or a nonstationary Gaussian shot noise through a filter. The performance index to be minimized consists of the covariances of both the structural responses and the control forces. Under these conditions, the optimal control law is a linear feedback control. The optimal control forces are obtained by solving a matrix Riccati equation. Applications of the optimal control to a multidegree-of-freedom structure, under stationary wind loads and nonstationary earthquakes, are demonstrated. It is shown that significant reduction in covariances of the structural responses can be achieved by the use of an active control system.

● 7.1-20 Benedetti, D. and Vitiello, E., **Input-output relations in the optimization of seismic protection,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 163, 13. (For a full bibliographic citation see Abstract No. 1.2-8.)

The determination of optimal levels of seismic protection is seen as an optimization problem. Relations among seismicity, building type and cost, resistance of existing buildings to be replaced, marginal cost of human life, and design criteria are obtained in an explicit format. This allows a sensitivity analysis between input (data on the existing situation and hypotheses) and output (design criteria) quantities.

● 7.1-21 Mahin, S. A. and Bertero, V. V., **Use of ductility factors in aseismic design,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 130, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

In inelastic analyses of structures, the maximum required deformations are commonly expressed in terms of ductility factors. Based on such factors, improved methods for preliminary seismic design and final detailing of critical regions have been suggested recently. After reviewing definitions of ductility factors, problems encountered in their application are briefly discussed, giving emphasis to the reliability of curvature ductility estimates obtained using conventional lumped, rather than realistic spread, plasticity models.

● 7.1-22 Papastamatiou, D. J., **Do we need design response spectra,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 131, 8. (For a full bibliographic citation see Abstract No. 1.2-8.)

Today structures are designed to resist earthquakes on the basis of expected time histories. This expected ground motion is either selected from strong-motion records, derived from peak values and design response spectra, or generated by stochastic models. The three different approaches are discussed in the light of earthquake source models. It is concluded that a stochastic approach based on a physical model of seismic sources constitutes a more fundamental way to view the problem.

7.1-23 Akhund-Zade, E. M., **Design of cylindrical shells with variable curvature for seismic loads** (K voprosu rascheta tsilindricheskoi obolochki peremennoi krivizny na seismicheskuyu nagruzku, in Russian), *Izvestiya Akademii Nauk Azerbaidzhanskoi SSR, 3*, 1974, 80-85.

Response of a thin cylindrical shell of variable curvature and constant thickness to seismic load is considered in a linear setting. A small parameter method developed by the author is used. The method is suitable for computer programming.

● 7.1-24 Kulkarni, R. B., **Decisions of optimum structural safety,** *19*, The John A. Blume Earthquake Engineering Center, Stanford Univ., May 1975, 316.

The various uncertainties and decisions involved in designing structures for optimum structural safety are discussed. Probabilistic descriptions of structural loads (including earthquake loads), load effects and resistances are presented. The optimum safety of beams and columns under different failure modes is examined. A parametric study and sensitivity analysis of the final results, and code calibration, design aids and integrated design examples are presented.

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● 7.1-25 Penzien, J., **Predicting the performance of structures in regions of high seismicity,** *EERC 75-33,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1975, 49. (NTIS Accession No. PB 248 130)

The complete seismic design process of certain important structures based on time-history dynamic analyses is traced from the initial preliminary design stage through the final stage of predicting lifetime performance to strong-motion earthquakes. Emphasis is placed upon (1) selection of sound design procedures, (2) consideration of field and laboratory evidence, (3) application of present-day knowledge, and (4) recognition of uncertainties involved in the complete process. It is concluded that meaningful predictions of performance can be made only when formulated in a probabilistic sense.

● 7.1-26 Bertero, V. V., **Identification of research needs for improving aseismic design of building structures,** *EERC 75-27,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1975, 97. (NTIS Accession No. PB 248 136)

This report discusses research needs in earthquake engineering for improving the earthquake-resistant (aseismic) design of building structures. Present knowledge is reviewed regarding problem areas of design and construction for achieving an economical, serviceable, and "safe" building located in an area of high seismic risk. After briefly discussing the importance of some aspects involved in the construction of an earthquake-resistant building, the report is devoted to reviewing the state-of-the-art in the following aspects involved in the design of such buildings: the establishment of design earthquakes; the selection of structural materials and structural systems; the prediction of the mechanical (dynamic) behavior of the structure which involves modeling of the structure, structural and stress analyses, and the proportioning and detailing of members, as well as their connections and supports; and the analysis of the reliability of the final design. In examining the state-of-the-art in each of the above aspects, the problems involved and the research needed are identified and discussed.

Some of the major conclusions drawn from the discussions presented indicate need for developing more reliable inelastic design spectra, isolation mechanisms, large earthquake simulator and pseudostatic facilities, new aseismic structural systems, damping devices for controlling structural response, and more realistic mathematical models to determine the reliability of the nonlinear behavior of different structural systems. A list of research needs is presented together with research priorities; guidelines for conducting the necessary investigations are offered.

The report ends by emphasizing the need to improve coordination and integration of national and international research programs in the field of earthquake engineering, as well as the need to translate the research results into information useful to design engineers and code officials.

● 7.1-27 Omote, S., Hanai, M. and Nagamatsu, S., **Occurrence rate of earthquake motion in Japan,** *Bulletin of the International Institute of Seismology and Earthquake Engineering,* 13, 1975, 101-118.

After defining the occurrence rate λ (V) of an earthquake motion larger than magnitude V as the number of times to be experienced at a location within a unit of time, the safety of a building, which was designed to resist earthquake motions up to V, can be evaluated numerically using the occurrence rate λ (V), under the assumption that the probability model of an earthquake occurrence can be represented by a Poisson process. In this case $1/\lambda$ (V) gives a return period of the earthquake motion V. In past studies, the expected maximum ground motion V was defined by that value of V where the return period is just equal to the length of time such as 50, 75, 100 or 200 years. A V as defined in the above method, however, does not take into consideration the evaluation of the safety of a building.

In this paper, discussions were extended to evaluate the safety of a building by introducing the relation between V and λ(V). As an example, using past earthquake data in Japan, the safety of a building having a lifetime of 50 years was calculated, in the probability of 90%.

In the course of calculation it is pointed out that the length of the period in which the earthquake data are available plays a very important role in evaluating the safety of that building.

7.2 Building Codes

● 7.2-1 Sharpe, R. L. *et al.*, **Nationally-applicable seismic design recommendations - A progress report,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 77-86.

The Applied Technology Council (ATC) in cooperation with the National Bureau of Standards (NBS) and the National Science Foundation - RANN Program is developing comprehensive seismic design recommendations which can be adopted by jurisdictions throughout the United States. The project is a major joint undertaking of the engineering profession and others in the professional community, including architects, earth scientists, building regulatory officials, code promulgating officials, researchers and the federal government. The project is part of the Cooperative Federal Program in Building Practices for Disaster Mitigation which was initiated in the spring of 1972 under the leadership of NBS. An initial planning phase was authorized in late 1973 under a contract from NBS. The present phase was started in Nov. 1974 and is scheduled for completion in 1976.

A brief description of the ATC, including its origin and the type of projects it has undertaken, is given. The scope, organization and philosophy of the present project and its status are then reviewed.

● 7.2-2 de Neufville, R., **How should we establish public policy on setting design codes or performance standards?**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 327–336.

The choice of a design code depends on the values we place on the benefits or on the costs of greater safety or higher performance. Experimental data demonstrate that the public's evaluation of any protection, against earthquake damage for example, is both a highly nonlinear function of its level and of the level of other benefits, and that it varies between different elements of society. As shown by a case study, these facts mean the most commonly discussed methods of evaluation for seismic codes—benefit-cost or risk-of-death analysis—may lead to incorrect and unacceptable recommendations. A criterion is proposed for deciding when approximate evaluations are appropriate and when a more complete assessment of the nonlinear values used by the different interest groups is required.

7.2-3 Heidebrecht, A. C., **Dynamic evaluation of overturning moment reduction factor used in static seismic loading**, *Canadian Journal of Civil Engineering*, **2**, *4*, Dec. 1975, 447–453.

The static seismic loading provisions of the 1975 National Building Code of Canada include, as do a number of other seismic codes, an overturning moment reduction factor in order to recognize that the overturning moment computed from the static load distribution is likely to be larger than the actual maximum dynamic moment. The reduction factors specified in the various codes have been based on empirical data and on relatively simplistic evaluations of the contributing effects. The purpose of this paper is to make a dynamic evaluation of the dynamic shear moment relationship and the reduction factor for a class of uniform shear wall-frame buildings subjected to earthquake motions as specified by several design spectra. The results are presented to show the effect of damping, natural period, and the particular response spectrum for different shear wall-frame stiffness proportions.

7.2-4 Humar, J. L. and Wright, E. W., **Shear and overturning moment for earthquake-resistant building design**, *Canadian Journal of Civil Engineering*, 2, *1*, Mar. 1975, 22–35.

The provisions of the present Canadian and U.S. seismic codes are examined with respect to their requirements on the distribution of seismic forces and overturning moments throughout the heights of building structures. Assuming the code design base shears to be correct, it is shown that the prescribed distribution of lateral forces may underestimate the shear forces in the upper stories of the building. It is further shown that the contribution of the higher modes is not directly related to the height-to-width ratio of the building, but rather to its fundamental period of vibration. By idealizing the building as an average uniform cantilever deflecting partly in a shear mode and partly in a bending mode and by taking a root-sum-square combination of the modal responses to a standard seismic acceleration spectrum, the envelope of the resultant maximum shears throughout the building height is obtained; the maximum overturning moments throughout the building height are obtained in a similar manner. By comparing these with the cantilever overturning moments computed from the shear envelope referred to above, the moment reduction factors applicable to the various levels of a building are calculated. New empirical relationships are then developed to approximate the shape of the maximum shear and overturning moment envelopes.

7.2-5 Taylor, D. A., **Progressive collapse**, *Canadian Journal of Civil Engineering*, **2**, *4*, Dec. 1975, 517–529.

This paper explains the nature of progressive collapse, with examples, and enlarges considerably on commentary C, supplement No. 4 of the 1975 National Building Code of Canada. Attendant philosophical problems related to code coverage and the design for progressive collapse are considered in discussions of risk, abnormal events that might initiate progressive collapse, and design procedures to reduce the risk of progressive collapse. An example illustrates some of these procedures and indicates how, in a general way, design problems may be approached.

● 7.2-6 ACI Committee 318, **Proposed revisions to: Building code requirements for reinforced concrete (ACI 318-71)**, *Journal of the American Concrete Institute*, **72**, *1*, Title No. 72-1, Jan. 1975, 1–8.

This study presents a number of revisions to the ACI Building Code. The revisions deal with reinforcement details, permissible shear stresses, reinforcement development length, permissible stresses in prestressed members, continuous prestressed members, prestressing ducts, and grouting of prestressed tendons.

7.2-7 Paulay, T. and Uzumeri, S. M., **A critical review of the seismic design provisions for ductile shear walls of the Canadian code and commentary**, *Canadian Journal of Civil Engineering*, **2**, *4*, Dec. 1975, 592–601.

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The 1975 Canadian Building Code for the design of reinforced concrete shear wall buildings in high seismic risk areas includes provisions that are new and significant. This paper critically examines some of these provisions, especially as they apply to cantilever shear walls. Clarifications in the definitions of curvature, member, and system ductilities are attempted. The relationship between curvature and system ductility is examined. Code provisions on allowable shear stress in the wall in the plastic hinge region and the provisions for the classification of the walls are discussed. Attention of the designer is drawn to some aspects of the code and the commentary that may result in structures of doubtful safety.

● 7.2-8 ACI Committee 313, **Proposed ACI standard: Recommended practice for design and construction of concrete bins, silos, and bunkers for storing granular materials,** *Journal of the American Concrete Institute,* **72,** *10,* Title No. 72-37, Oct. 1975, 529–548.

This recommended practice gives material, design and construction requirements for reinforced concrete bins, silos, and bunkers and stave silos for storing granular materials. It includes recommended design and construction criteria based on experimental and analytical studies plus worldwide experience in silo design and construction.

Bins, silos, and bunkers are special structures, posing special problems not encountered in normal building design. While this recommended practice refers to "Building Code Requirements for Reinforced Concrete" (ACI 318) for many applicable requirements, it provides supplemental detail requirements and ways of considering the unique problems of static and dynamic loading of silo structures. Much of the method is empirical, but this recommended practice does not preclude the use of more sophisticated methods which give equivalent or better safety and reliability.

This recommended practice sets forth recommended loadings and methods for determining the stresses in the concrete and reinforcement resulting from these loadings. Methods are recommended for determining the thermal effects resulting from stored material and for determining crack width in concrete walls due to pressure exerted by the stored material. Appendixes provide recommended minimum values of overpressure and impact factors.

● 7.2-9 ACI Committee 313, **Commentary on recommended practice for design and construction of concrete bins, silos, and bunkers for storing granular materials,** *Journal of the American Concrete Institute,* **72,** *10,* Title No. 72-38, Oct. 1975, 549–565.

This commentary presents some of the considerations and assumptions of ACI Committee 313 in developing the provisions of the "Recommended Practice for Design and Construction of Concrete Bins, Silos, and Bunkers for Storing Granular Materials." It also provides suggested methods for calculating crack width, through-the-wall temperature gradient due to hot stored materials and the effect of eccentric discharge.

Comments on specific provisions of the recommended practice are made, using the corresponding chapter and section numbers of the recommended practice. A list of selected references is given at the end of the commentary.

7.3 Design and Construction of Buildings

7.3-1 Gerasimov, V. V. and Maletina, Z. M., **Evaluation of the effects of seismic conditions on the economics of housing construction in eastern Siberia** (Otsenka vliyaniya seismicheskikh uslovii v rayonakh vostochnoi Sibiri na ekonomiku zhilishchnogo stroitelstva, in Russian), *Sbornik nauchnikh trudov Sibirskogo zonalnogo nauchno-issledovatelskogo instituta tipovogo i eksperimentalnogo proektirovaniya zhilishchnikh i obshchestvennykh zdanii, 6,* 1973, 129–134.

Problems in improving the structural design of apartment buildings in the seismically active areas of Siberia and the Soviet Far East are considered. Technological and economic aspects of various design features to increase the earthquake resistance of buildings are discussed.

● 7.3-2 Watabe, M., **Aseismic structural systems for buildings: Part 1,** *Technocrat,* 7, *1,* Jan. 1974, 99–107.

The basic principles for the earthquake-resistant design of buildings are discussed in this first part of a two-part paper (see Abstract No. 7.3-3 for Part 2). The influence of the number of stories and the rigidity of columns and beams on the natural periods and mode shapes of a structure is investigated by examining a symmetric, one-span frame of n stories. Using a similar method of analysis, the author analyzes a framed structure with shear walls; the results are presented in tabular form. In conclusion, the hysteretic characteristics are shown for various types of structures subjected to lateral forces.

● 7.3-3 Watabe, M., **Aseismic structural systems for buildings: Part 2,** *Technocrat,* 7, *2,* Feb. 1974, 86–98.

In this second part of a two-part paper (see Abstract No. 7.3-2 for Part 1), the design of reinforced concrete, masonry and steel structures and composite structures with reinforced concrete is examined. Photographs of earthquake damage to reinforced concrete structures are included; particular attention is given to the design and arrangement of reinforced concrete frames, shear walls and columns. In the case of steel structures and composite structures with reinforced concrete, the design of foundations, joints and tensile and compressive members is examined. Several design philosophies for masonry construction also are presented.

7.3-4 Popoff, Jr., A., **Design considerations for a precast prestressed apartment building—Design against progressive collapse,** *Journal of the Prestressed Concrete Institute,* **20,** 2, Mar.-Apr. 1975, 44-57.

The paper is presented in two parts. The first part reviews existing and developing code provisions pertaining to progressive collapse. A design philosophy based on seismic design practices is presented; it is suggested that this design philosophy is the proper approach to design against progressive collapse.

The application of the suggested design philosophy is presented in the second part of the paper. It consists of a commentary and simple calculations from which a series of connection details and minimum reinforcement requirements is derived.

7.3-5 Kulka, F., Lin, T. Y. and Yang, Y. C., **Prestressed concrete building construction using precast wall panels,** *Journal of the Prestressed Concrete Institute,* **20,** *1,* Jan.-Feb. 1975, 62-73.

This paper describes the design and construction of multistory buildings using precast elements integrated into walls and floors by reinforcing steel and post-tensioning. Precast wall panels are connected to form structural walls by casting in place spandrel beams and columns using wall panels as forms. This transforms the usually inactive curtain walls into vertical and lateral load resisting elements. The response of these buildings to lateral forces is studied, first following building code requirements and then using catastrophic earthquake spectra. The advantages and problem areas of such construction are discussed.

7.3-6 Kondratev, R. B. and Nudelman, E. G., **On the design of diaphragms from prefabricated floor elements for horizontal loads** (O raschete diafragm iz sbornykh poetazhnykh elementov na gorizontalnye uzlovye nagruzki, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1,* 1974, 45-49.

In this paper a design method for one-column and two-column diaphragms is presented which is used in Leningrad for multistory building design. An example is also given.

● 7.3-7 McCue, G. M. *et al.*, **Building enclosure and finish systems: Their interaction with the primary structure during seismic action,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 235-244.

The research described in this paper considers a building as a collection of interacting systems, where the primary structure both acts on and is acted upon by architectural systems, and where all systems participate in the building response. This position challenges the conceptual framework on which much of current design is based.

A summary of the experience gained from earthquakes provides a framework for discussing the problems associated with past assumptions. An interpretation of current building practices, followed by an examination of building motions and the various levels of interaction between the primary structure and architectural systems, leads to the delineation of new conceptual models for design and analysis in order to mitigate damage.

● 7.3-8 Lefter, J. and Colville, J., **Reinforcing existing buildings to resist earthquake forces,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 226-234.

A method is presented for evaluation of the earthquake safety of existing buildings constructed of reinforced concrete frames with masonry infill panels. Conventional analyses of buildings of this type ignore the masonry because of its assumed unreliable structural strength. However, the masonry may have a marked effect on the response of the structure to seismic motion and may even precipitate collapse of the building. Therefore, the method presented takes into account the response of the masonry to both in-plane and out-of-plane forces. If the strength and stiffness of the frame-wall system are known, the remainder of the analysis can be based on conventional practices once the earthquake forces are computed. In conclusion, considerations involved in the reinforcing of such buildings are presented.

● 7.3-9 Freeman, S. A., Nicoletti, J. P. and Tyrrell, J. V., **Evaluation of existing buildings for seismic risk—A case study of Puget Sound Naval Shipyard, Bremerton, Washington,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 113-122.

The risk evaluation procedure, developed for analysis of the structures at the Puget Sound Naval Shipyard, is discussed. During the study, it was demonstrated that it was possible to perform a worthwhile evaluation of existing structures at reasonable cost. The study also indicated that the condition of most structures in the naval shore establishment was good with respect to the ability of the structures to resist seismic forces; a few structures needed

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strengthening, however. A program to carry out necessary investigations is now being developed.

● 7.3-10 Highlands, D., Oppenheim, I. and Strain, J., **Hospital design for earthquake performance: Vertical circulation,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 347-356.

The effects of nonstructural damage on hospital performance during disasters are examined. In particular, the design of vertical circulation systems such as elevators and stairs is discussed. The role of hospitals during disasters is described first. Then, the general performance requirements for the design itself are explained. Next, the role of vertical circulation in providing this performance is developed. The engineering aspects for the earthquake design of elevators and stairs are then summarized. Last, a set of conclusions and recommendations is given in an attempt to suggest actions to be taken by designers and users of hospital facilities.

● 7.3-11 Pecknold, D. A., **Slab effective width for equivalent frame analysis,** *Journal of the American Concrete Institute,* **72,** *4,* Title No. 72-13, Apr. 1975, 135-137.

In the preliminary analysis of slab-column structural systems subjected to lateral loads, it is often assumed that an "effective width" of slab acts as a beam. An expression for the effective width of a typical interior panel is obtained, and useful results are given for a wide range of slab aspect ratios and column sizes.

7.3-12 Shakhmeri, I. M., **Efficiency of lightweight structures in seismic regions** (Effektivnost primeneniya oblegchennykh konstruktsii v seismicheskikh rayonakh, in Russian), *Trudy TsNII promyshlennykh zdanii i sooruzhenii, 39,* 1975, 55-60.

Engineering and economic parameters of one-story reinforced concrete or steel frame industrial buildings designed for regions with high seismicity are compared to those without seismic design features. Techniques of mathematical statistics and the method of least squares are employed to construct a polynomial model representing the proportional effects of various factors in design of reinforced concrete or steel frame buildings.

7.3-13 Poliakov, S. V., Zolotov, A. B. and Kirikov, B. A., **On design of structures with deformable floor slabs using real earthquake records** (O raschete konstruktsii zdanii s uchetom deformiruemosti perekrytii po realnym tapisyam zemletryasenii, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2,* 1975, 37-40.

The elastic behavior of structures with yielding foundations, floor slabs and vertical elements is analyzed using earthquake accelerograms. The method presented may be useful in the preparation of a new code of design requirements for earthquake resistant buildings.

7.3-14 Tairova, N., **Design of light concrete hinged wall panels in earthquake-resistant frame buildings** (Konstruktsii legkozhelezobetonnykh navesnykh stenovykh panelei seismostoikikh karkasnykh zdanii, in Russian), *Sbornik nauchnykh trudov zonalnogo nauchno-issledovatelskogo instituta tipovogo i eksperimentalnogo proektirovaniya zhilishchnykh i obshestvennykh zdanii, Tbilisi,* 7, *1,* 1973, 36-40.

Design of light concrete hinged wall panels of frame-panel buildings in seismic areas is discussed. Such panels are used as external walls with ventilated internal air space contributing to the temperature control of the building and are especially useful in hot and humid climatic conditions.

● 7.3-15 Williams, R. L., **A procedure for the analysis and design of ductile reinforced concrete frame buildings of moderate height,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 8, *4,* Dec. 1975, 260-272.

A procedure is presented in step-by-step form for designing and detailing a reinforced concrete frame building to the requirements of DZ4203 (Draft New Zealand Loading Code). Adequate member ductility is provided by means of a capacity design approach. All members are permitted to form a large number of plastic hinges by which energy is dissipated without brittle failure. Further ductile detailing is given for all other locations where accidental hinges could occur and to limit excessive deflections that may result from deterioration of beam-column joints.

● 7.3-16 Hart, G. C., DiJulio, Jr., R. M. and Lew, M., **Torsional response of high-rise buildings,** *Journal of the Structural Division, ASCE,* **101,** *ST2,* Proc. Paper 11126, Feb. 1975, 397-416.

Ambient and earthquake response records obtained in several southern California high-rise buildings are analyzed. Building translational and torsional natural periods are estimated and compared. Ambient response is found to be an important indicator of earthquake response. Torsional building response resulting from ambient and earthquake excitation was found to be significant. A design spectrum is developed representing a standardized torsional ground motion of the intensity of the 1940 El Centro earthquake.

● 7.3-17 Velkov, M., **Aseismic design of 24 storey hotel de-luxe, Skopje,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 8, 2, June 1975, 128-141.

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This paper presents the structural design and dynamic analysis of a 24-story hotel in Skopje. Applying the latest concepts for seismic stability and safety of structures, i.e. the plasticity criteria and plastic excursion deformations, the design of the structural system was accomplished. The system itself is a reinforced concrete frame combined with R.C. framed walls. The framed walls are designed to act as seismic energy absorbers.

The mathematical model was formulated while the input data concerning the stiffness characteristics and deformations of the infilled walls were based on experimental results obtained in Japan. The data obtained for the optimal system show that the structure satisfies completely all the requirements imposed by the seismicity criteria of the site.

● 7.3-18 Arora, J. S., Haug, Jr., E. J. and Rim, K., **Optimal design of plane frames,** *Journal of the Structural Division, ASCE,* **101,** *ST10,* Proc. Paper 11633, Oct. 1975, 2063–2078.

This paper presents an application of state space optimization techniques to the optimal design of plane steel frames. AISC code requirements are imposed, along with displacement, natural frequency and member size constraints. A general structural design problem is defined and is then specialized to the case of plane frames. Results for three example problems are obtained with a computer program developed for the purpose. Results are compared with solutions available in the literature. New results are presented for cases in which multiple failure modes are imposed on the structure.

● 7.3-19 Oppenheim, I. and Desai, K., **Masonry structures in earthquakes,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 363–366.

Two recent papers concerning masonry construction and earthquakes are summarized. The first paper suggests the use of yield line analysis to evaluate the lateral strength of single-story unreinforced masonry walls. This method results in a very simple earthquake failure criterion. The second paper discusses the effect of vertical ground motion on floor or roof systems and the resulting unloading of the masonry walls. This unloading causes a reduction in the predicted lateral strength.

The typical construction of Ahmedabad (Gujarat), India, is surveyed, and three building types chosen for analysis. Their predicted strengths are not widely disparate, although, theoretically, traditional construction is slightly superior to modern construction, mostly because of thicker walls. Furthermore, the traditional wood joist roof construction is superior to alternative methods of construction.

● 7.3-20 Keightley, W. O., **Interlocking bricks for earthquake-resistant houses,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 367–374.

Two methods are presented for the mechanical interlocking of bricks, to be used in addition to mortar, for increasing the earthquake resistance of masonry houses. Static tests of small assemblages, using one method, show markedly increased toughness at little increase in cost of materials. Shaking tests of actual houses are needed to prove the worth of the methods.

● 7.3-21 Rao, J. V. N. and Kapoor, M. P., **Optimum aseismic design of multistory frames,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 245–252.

The problem of optimum seismic-resistant design of multistory frames is cast as a nonlinear programming problem. The multistory frame is idealized as a shear beam subjected to ground acceleration represented by white noise. The objective function is the weight of the frame, and the moments of inertia of the columns of different stories are the design variables. Constraints have been imposed on the upper bound of the probability of failure—defined as the probability that the stresses due to earthquake acceleration exceed the yield stress of the material of the column. Both upper and lower bound solutions have been obtained. They differ by not more than ten per cent, which indicates that the upper bound solution is not too conservative but fairly close to the exact solution. At the optimum, all the stories simultaneously reached the limits on the upper bound of the probabilities of failure. As damping increases, the optimum weight decreases. As the allowable limit on the probability of failure decreases, the optimum weight decreases.

● 7.3-22 Bolt, B. A. *et al.*, **The study of earthquake questions related to Veterans Administration hospital facilities,** *Bulletin of the Seismological Society of America,* **65,** *4,* Aug. 1975, 937–949.

After the San Fernando earthquake, Feb. 9, 1971, the Veterans Administration undertook investigations and research to develop requirements for earthquake-resistant design for VA hospital facilities. Veterans Administration hospital sites number 170 across the United States. Site-evaluation procedures and design criteria have now been developed. Evaluations of peak ground accelerations for engineering assessments at hospital sites in zones 3 and 2 are available. In a parallel strong-motion recording program, 58 accelerometers already have been placed in VA hospital facilities across the country. Attention has been given to operations, utilities and access after destructive earthquakes, particularly emergency services that must serve the hospitals' own patients and community. Standards for protection of nonstructural elements and equipment of hospitals have been established.

● 7.3-23 Medvedeva, E. S., **Use correlative dependence between accelerations in design,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 80, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Relations of measured accelerations of vertical and horizontal components of the vibrations of buildings and the ground are analyzed. Elementary statistical treatment of the results of measurements of vibrations of buildings with different number of stories with framed construction is presented. Ratios between maximal vertical and horizontal accelerations during strong earthquakes are equal on the average to 0.56 when the root-mean-square deviation equals 0.23 and dispersion equals 0.05. During weak earthquakes, these relations are less and on the average equal 0.45.

● 7.3-24 Kligerman, S. I. and Medvedyev, M. I., **Structure of an antiseismic skeleton frame with three-axis compression,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 115, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The collarless seismic-resistant skeleton frame discussed in this paper represents an improvement over a commonly used skeleton frame structure which has prefabricated floors compressed in two directions with the help of stressed reinforcement. In the suggested structure, stiffening diaphragms also are subjected to compressing with the help of vertical reinforcement, which turns the diaphragms from cantilevers into beams with one end fixed and another elastically supported. This reduces the bending moments within the diaphragms and increases the reliability of diaphragms under seismic effects.

7.3-25 Kato, B. and Akiyama, H., **Aseismic limit design of steel rigid frames** (in Japanese), *Transactions of the Architectural Institute of Japan, 237,* Nov. 1975, 59-65.

Response analyses were conducted up to frame collapse states, using realistic force characteristics of rigid steel frames. Analytical results were consistent with Housner's energy concept.

The proposed procedure for the seismic-resistant limit design of rigid steel frames is summarized as follows: (1) Calculate the plastic deformation response of an elastic-perfectly plastic vibrational system with the same natural period and the same yield base shear coefficient as those of the structure examined in this paper. (2) After referring the restoring force characteristics pertinent to the structure, the deformation response of the structure can be converted by an equation presented in the paper. (3) Safety of the structure against collapse can be assured by a criterion presented.

7.3-26 Korchinskii, I. L., Borodin, L. A. and Duzinkevich, M. S., **Design of steel frames for seismic loadings incorporating plastic behavior of joints** (Raschet metallicheskikh karkasov na seismicheskie vozdeistviya s uchetom obrazovaniya plasticheskikh sharnirov, in Russian), *Promyshlennoe stroitelstvo, 2,* 1974, 40-42.

The principles of earthquake-resistant steel frame design are discussed. The design should ensure that column deformations remain within the elastic range. Plastic deformations are allowed in those portions of the beams located away from the beam-column joints. Results of experimental investigations of the energy absorption characteristics and strength of various types of beams are presented. The basic premises of steel frame design incorporating plastic behavior of joints are examined.

7.3-27 Ishimaru, S., **Ductility factor control method: On the frame system having strong-columns and weak-girders** (No. 2) (in Japanese with English summary), *Transactions of the Architectural Institute of Japan, 233,* July 1975, 61-70.

This paper presents a new design procedure for obtaining yield strength moments of all girders of a frame building. The procedure satisfies the condition that the response ductility factors of the girders approach the specified values, while the columns remain elastic.

The procedure is applied to a 10-story, single-bay frame model. The design ductility factors for both ends of all the girders are specified as 5.0 when the frame is subjected to the north-south and the east-west components of the El Centro earthquake and to the north-south component of the Taft earthquake, with a maximum acceleration of 100 gal.

A nonlinear response analysis was carried out with the condition that the columns remain elastic. The results are shown. The computed ductility factors agree fairly well with the design ductility factors. The ratio of the response values of the moment of columns to the predicted column moments is shown. It also is found that the response values nearly equal the given ones. In order to check the reliability of this method, the nonlinear time history curves of the story displacement of the frame having the given yield moments are compared with those calculated by modal analysis. Good agreement is found in every case.

● 7.3-28 El-Hafez, M. B. and Powell, G. H., **Computer aided ultimate load design of unbraced multistory steel frames,** *EERC 73-3,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1973, 195. (NTIS Accession No. PB 248 315)

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A general procedure for the design and analysis of multistory unbraced steel frames, suitable for computer formulation and solution, is presented.

Two computer programs are described, one which produces automated ultimate load designs, and a second which analyzes these preliminary designs to study their behavior and determine their collapse loads. The preliminary design may be designed for minimum beam cost using linear programming and may satisfy service deflection limitations. The inelastic analysis technique used takes into account the PΔ effect and panel zone deformations, in addition to other important influences.

The complete building, which may contain a number of parallel frames, may be designed and analyzed. Torsional behavior of the building is ignored. There are no limitations on the number of bays, stories or frames other than the capacity of the computer used in the design and analysis. A strong column-weak girder design concept is used, when plastic hinges can form only in the beams or panel zones. Column hinges are not permitted. Subassemblage concepts for multistory buildings are discussed, a single-story subassemblage is proposed, and the behavior of a typical subassemblage is examined in detail. The effects of different assumptions and boundary conditions on the behavior of the subassemblage are examined.

The inelastic analysis technique used in the analysis program is described. A linearized step-by-step procedure is used. The direct stiffness method and a substructuring technique are used to formulate the tangent stiffness. Panel zone deformations are included by means of an elasto-plastic panel element at the beam-column connections.

The preliminary design procedure is described. Two different types of preliminary designs are possible. The first makes use of a generalized plastic moment at each floor, which is used to relate the strength of the floor to the external loads. The second procedure makes use of linear programming to obtain preliminary designs which satisfy both strength and service deflection limitations. The second procedure may be used to produce preliminary designs with minimum beam cost.

A series of examples is presented to illustrate the design and analysis procedures.

● 7.3-29 Kamil, H. and Bertero, V. V., **A methodology for efficient and reliable design of high-rise structures under dynamic loads,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 162, 18. (For a full bibliographic citation see Abstract No. 1.2-8.)

A procedure is presented for an efficient and reliable earthquake-resistant design of high-rise structures. As an example, an improved efficient procedure for the earthquake-resistant design of an unbraced multistory frame is presented. A strong column-weak girder type of design technique is used in the inelastic range. The procedure consists of a preliminary design technique using a response spectrum approach, a nonlinear dynamic analysis technique using a yield surface approach, and a final optimum design technique using a linear programming approach. Ductility requirements are taken into consideration at each stage, in addition to other design criteria.

A method for determining the probability of failure in the nonlinear range for the same structure also is demonstrated. The frame is assumed to be a "series" type of system, made up of individual stories as the links, so that if one story fails the whole system fails. Each story, in itself, is considered to be a "parallel" type of subsystem.

● 7.3-30 Walker, N. D. and Pister, K. S., **Study of a method of feasible directions for optimal elastic design of frame structures subjected to earthquake loading,** *EERC 75-39,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1975, 101.

This report deals with optimum design of elastic single-bay multistory rigid frames subjected to dead loads and earthquake-generated horizontal ground motion. The basis design problem is cast in the format of mathematical programming. Expressions necessary to solve the problem via the nonlinear programming technique of a method of feasible directions are obtained. For a particular choice of design objective and constraint functions, along with a typical pseudo-velocity response spectrum characterizing the ground motion, examples of the design of one-, two-, and eight-story frames are provided. These examples serve to develop insight into the nature of the structural optimization problem under study as well as the operating characteristics of the feasible directions algorithm.

7.4 Design and Construction of Nuclear Facilities

● 7.4-1 Stevenson, J. D., **Part 1: Engineering and management guide to seismic design requirements for nuclear plant equipment,** Nuclear Structural Systems Assn. Inc., Pittsburgh, 1974, 82.

This guide, Part 1 of a two-part report, has been prepared to assist engineering and management personnel in the proper preparation and evaluation of seismic design requirements for Seismic Category I components and structures to meet good nuclear design practice and the anticipated licensing requirements of regulatory agencies. The guide is specifically designed to acquaint individuals having a general engineering and management background with the terminology and concepts of seismic design and analysis. Included in the guide are typical equipment

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specifications which may be used as the basis for defining or evaluating the seismic design adequacy of components and structures and a brief discussion of seismic analysis costs.

Part 2 covers tornadoes, missiles and pipe breaks.

● 7.4-2 Russcher, G. E., **Comparative analysis of nuclear reactor control system design,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 502–511.

In this study an alternate conceptual design of a safety rod system was compared with a prototypal system design to assess the relative functional reliabilities of each under seismic design conditions. The comparative methods utilized standard success tree and decision tree techniques to determine the relative figures of merit. The study showed that (1) the methodology utilized can provide both qualitative and quantitative bases for design decisions regarding seismic functional capabilities of two systems under comparison; (2) the process emphasizes the visibility of particular design features that are subject to common mode failure while under seismic loading; and (3) minimal improvement is available in overall system seismic performance of an independent conceptual design; however, the system would be subject to a new set of operational uncertainties which would have to be resolved by extensive development programs.

● 7.4-3 Jennings, P. C. and Guzman, R. A., **Seismic design criteria for nuclear powerplants,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 474–483.

A summary is presented of the method, developed by the authors during the past two years, for selecting design spectra for nuclear power plants. In the course of working out the details of the approach, it was found useful to reexamine a number of concepts, including the use of response spectra or peak values of ground motion parameters, the shape of the design spectra, problems in attenuation and scaling, and the use of motions on the ground surface or bedrock motions.

There is nothing fundamentally new in the suggested approach, although some of the features may not have been applied to the problem of selecting design spectra for nuclear power plants in the way the authors suggest. The approach is applied only to nuclear power plants in this paper but it is not limited to this application; a somewhat similar approach has been applied to electrical facilities.

Some guidelines used in developing the approach are described. A brief explanation of the steps involved in the application of the approach is given. The emphasis is upon explaining the basic features of the method; a more detailed description of the mechanics of application, including examples and test cases, has been given previously by the authors.

● 7.4-4 Liao, E. N. and Marda, R. S., **On static loads method for seismic design of nuclear power plant facilities,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 484–494.

Multiple-degree-of-freedom systems with varying mass and stiffness characteristics are analyzed. The static load factor is formulated in connection with the modal analysis response spectra technique. By extremizing the expression for the static load factor, the upper bound of the static load factor is obtained for two-degree-of-freedom systems with simply supported or cantilever boundary conditions. The result is extended to determine the maximum values of the static load factor for three-degree-of-freedom systems. In addition, numerical results are presented to illustrate the upper bound of the static load factor as a function of the mass ratio for two-degree-of-freedom as well as three-degree-of-freedom systems.

● 7.4-5 McDonald, C. K., **Seismic qualification by analysis of nuclear power plant mechanical components,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 529–537.

Several models are presented which have been extensively used for both the dynamic and the quasi-static seismic analysis of selected mechanical components of nuclear power plants. The components covered include vertical and horizontal pumps and drivers, vertical and horizontal tanks, and fans. The primary emphasis of the models presented is upon qualification of the components by analysis, either dynamic modal or quasi-static. All models discussed have been formulated for solution by computer; a number of excellent computer codes are available for the solution of these problems.

● 7.4-6 Mehta, D. S., **Current USAEC seismic requirements for nuclear power plants,** *Bulletin of the Indian Society of Earthquake Technology,* **12,** 2, Paper No. 152, June 1975, 65–73.

This paper provides current (1975) USAEC seismic requirements for nuclear power plants.

7.4-7 Kar, A. K. and Sinha, S. S., **Seismic supports for electrical cable systems,** *Journal of the Power Division, ASCE,* **101,** *PO1,* Proc. Paper 11464, July 1975, 95–110.

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Seismic Category I supports for electrical conduit and cable tray systems are described. Types of supports and their analysis, design, and installation also are presented. Approximate formulas for simplified models are given to greatly facilitate the design. Field conditions and other factors, important in the behavior of the supports under seismic conditions, are considered. Recommendations on the damping coefficients are made.

● 7.4-8 Nori, V. V. *et al.*, **Response of a typical reactor building to strong motion earthquake,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 7-16.

A reactor building housing major components within a containment structure, an internal structure supporting various equipment, a heavy reinforced concrete vault housing a reactor unit and major equipment are idealized to a multidegree lumped-mass system. Response of the reactor building to a strong-motion earthquake is studied by idealizing the multidegree-of-freedom system as a suitable lumped-mass system and by analyzing the system using the response spectrum technique.

In this paper, the authors outline briefly the procedure used by them to analyze a typical reactor building subjected to a design basis earthquake of the El Centro type. Effects of soil-structure interaction have been included in the analysis by considering translational and rocking soil springs.

The main objectives are twofold: first, to emphasize the effect of variation of soil properties in modifying the response of the reactor buildings founded on different types of strata and, second, to evaluate a criterion for arriving at a weighted damping factor based on energy stored in different systems in the building during an earthquake. The results presented are based on the use of a smoothed response spectrum, as suggested by Newmark, for an earthquake with ground acceleration of 0.33 g.

● 7.4-9 Arya, A. S. and Thakkar, S. K., **Seismic analysis of hyperbolic cooling towers,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 25-34.

Assuming hyperbolic cooling tower structures to be a bending shear cantilever, the authors compute the free vibration characteristics of the towers using the transfer matrix approach. A wide range of tower geometrical dimensions is considered. The response of the towers to earthquake motions, represented by average acceleration spectra, is analyzed. As a result, realistic distribution of earthquake forces along the height is achieved. The data included is of direct use for design. A simplified dynamic analysis procedure that arrives at design values of shear and moments at various sections is presented, along with all required data.

● 7.4-10 Arya, A. S., Chandrasekaran, A. R. and Thakkar, S. K., **Permissible stresses and damping factors in nuclear power plants,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 2, Nov. 1974, 21-29.

Various elements affecting the required reserve of strength in nuclear power plant structures and components under different earthquake conditions are discussed in detail in order to determine the factors of safety or load factors. Allowable stresses are proposed for nuclear power plant structures in relation to design-basis earthquakes. Considering the stress levels reached in the structures, the authors also propose equivalent viscous damping factors for two design earthquakes.

● 7.4-11 Lou, Y. S. and Lepore, J. A., **Design earthquake selection and design criteria for nuclear components,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 124, 9. (For a full bibliographic citation see Abstract No. 1.2-8.)

The analysis of structures subjected to earthquakes, as well as in the seismic design of equipment, is only as realistic as the assumed input excitation. It is common practice, in nuclear power plant seismic analyses, to postulate certain forms of the forcing function to represent the design earthquake. The concept of seismic loading reduction and criteria for design earthquake selection are introduced in this paper. Various engineering practices currently in use in the analysis of nuclear components are discussed and criteria for seismic design of components and for design earthquake selection are recommended.

7.5 Design and Construction of Miscellaneous Structures

● 7.5-1 Okubo, T., **Aseismic considerations of transportation systems,** *Technocrat,* 7, 7, July 1974, 80-98.

Principles to be followed in the planning of transportation systems that are to be located in seismically active areas are discussed. Earthquake-resistant design standards are covered in general and specifically as they apply to highway bridges and oil pipelines. The final section of the paper includes photographs and descriptions of earthquake damage done to such transportation systems as highways, railways and water supply systems. Specific recommendations for improvement in the planning and design of each of these types of systems are also given.

● 7.5-2 Newmark, N. M., **Seismic design criteria for structures and facilities—Trans-Alaska pipeline system,**

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Proceedings of the U.S. National Conference on Earthquake Engineering-1975, Earthquake Engineering Research Inst., Oakland, June 1975, 94–103.

The author's recommendations for the seismic design criteria for structures and facilities of the trans-Alaska pipeline system are described. Included are a discussion of actual versus effective earthquake motions and descriptions of the design seismic motions used, the elastic response spectrum considered applicable, and the recommended design spectra which take into account appropriate amounts of inelastic behavior. The seismic design classification used is described together with the damping and ductility factors pertinent to the various classes adopted.

7.5-3 Chirkov, V. P., **Strength of compressed concrete elements under stationary random loads** (O raschete resursa betonnykh szhatykh elementov pri statsionarnom sluchainom nagruzhenii, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1*, 1974, 27–30.

A method is given for determining the strength and reliability of compressed concrete elements subject to loads which may be characterized as stationary Gaussian random processes.

The technique presented is based on an application of the general theory of accumulation of defects and takes into account the history of past loads. It allows the determination of the strength and reliability of compressed concrete elements and the evaluation of the service life of elements such as beams supporting cranes, reinforced concrete railroad ties, bridge piers, etc.

7.5-4 Uchida, K., **Tentative proposal for dynamic earthquake resistant design of tall reinforced concrete chimneys** (in Japanese), *Transactions of the Architectural Institute of Japan, 211*, Sept. 1973, 27–35.

In 1966 the author found through dynamic response analysis that tall reinforced concrete chimneys designed according to the Japanese seismic code are very strong in their bottom portions but extremely weak in their upper portions. In order to correct this, the author here establishes a tentative proposal using the earthquake-resistant design method, namely, that such parameters as chimney heights, chimney proportions, foundation conditions, damping assumptions and earthquake waves be selected for investigation of the vibration characteristics of tall chimneys by means of the direct earthquake response analysis. A tentative method for manual calculation of dynamic earthquake forces acting on chimneys is proposed on the basis of the analyzed vibration characteristics.

7.5-5 Lombardo, V. N., **Design of arch dams for seismic loads and failure at sectional and block joints** (Raschet arochnykh plotin na seismicheskie vozdeistviya s uchetom raskrytiya sektsionnykh i blochnykh shvov, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94*, 1974, 14–20.

Design of arch dams for seismic loading is discussed. In the first approximation, the method presented allows for the effects connected with failure at sectional and block joints. A mathematical formulation of the problem is given. The solution is based on numerical integration of the dynamic equations of the theory of shells using the explicit difference method.

7.5-6 Semenov, I. V., **Structural design of concrete dams for seismic loads** (Raschety ustoichivosti betonnoi plotiny pri seismicheskom vozdeistvii, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhnike, 94*, 1974, 20–25.

Shear resistance of dams is investigated by regarding the dam as a rigid block on top of an elastic halfspace undergoing horizontal and vertical vibrations.

The seismic disturbance is represented as a stationary random process. Comparing calculations using real seismograms to those using a stationary random process to represent seismic activity, the author finds that the latter method leads to excessively large acceleration values for the dam.

● 7.5-7 Baron, F. and Pang, S. H., **Seismic response of a long multi-span highway bridge**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 196–205.

Seismic studies are being made of a long multispan bridge proposed for a crossing of the lower arm of the San Francisco Bay. The studies consist of three phases: Phase 1 in which a preliminary design is investigated and a set of seismic design criteria is established; Phase 2 in which alternate designs, various joint types and structural articulations are studied; and Phase 3 in which a final design is selected and analyzed for various ground motions, including ground surface motions which propagate along, oblique and transverse to the longitudinal axis of the bridge. At the time of the writing of this report, Phase 3 was in progress. This report describes the results of Phase 1.

● 7.5-8 Hall, W. J. *et al.*, **Observations on the process of equipment qualification**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 495–501.

Some observations on the overall process of seismic qualification of equipment are presented. The interrelationship is described of three groups involved in the manufacture and use of the final product or system: the final user,

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the system assembler and the component manufacturer. Current literature on equipment qualification to meet seismic design requirements inadequately discriminates between these three groups. Despite differences in constraints and elements under the direct control of each of these three groups, they must provide a final system that is capable of qualification and that meets functional requirements. It is hoped that attention to the interrelationship problems between these three groups will help to clarify an area of major importance and will lead to procurement of equipment with improved functional capability at reasonable cost.

As an example of final user considerations, the approach employed in the trans-Alaska pipeline equipment procurement is described. In addition, brief mention is made of nuclear power plant equipment qualification requirements, as well as the equipment qualification requirements of public utility and transportation systems.

● 7.5-9 Newmark, N. M. and Hall, W. J., **Pipeline design to resist large fault displacement,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 416–425.

In this paper the capability of a pipe to resist fault motions corresponding to total fault displacements of 10 ft and greater is considered. The pipe is buried at several depths and is made of one of three possible grades of steel and two wall thicknesses. The capability of a pipe buried in soil to resist fault motions is generally greater than its capability in rock. For conservatism, the values and conditions used in this paper are taken as consistent with a pipe in a trench in rock.

General conclusions are presented regarding the depth of cover that might be used for different grades of pipe in order to assure the capability of resisting the fault motions. In some instances, especially for the deeper depths and the higher grades of steel, it may be necessary to avoid regions where the angle of the fault plane with the pipe axis is so small that nearly all of the fault displacement is transmitted to the pipe as a longitudinal deformation in the pipe. Some typical results of calculations also are presented.

● 7.5-10 Townsend, W. H., **Seismic design of utility equipment anchors,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 426–434.

The a-c harmonic filter reactors at the Sylmar Converter Station in Southern California are analyzed for various earthquake loadings in order to present a rational design method for designing utility anchor bolts. Placing the anchor bolts 30 degrees from vertical will reduce the normal stresses to less than half the stresses of vertical anchors for this piece of equipment and provide a more ductile anchor for inelastic loading.

● 7.5-11 Merz, K. L., **Nonstructural hospital systems in the earthquake environment,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 337–346.

The identification, priority of importance, and behavior of the nonstructural systems of hospitals during earthquakes are discussed. Recommendations for upgrading the seismic resistance of existing nonstructural hospital systems are given.

● 7.5-12 Lavania, B. V. K., **Tehri rockfill dam,** *Journal of the Geotechnical Engineering Division, ASCE,* **101,** *GT9,* Proc. Paper 11587, Sept. 1975, 963–976.

The 260-m high rockfill dam of the Tehri Project in India is to be placed at a site that has complex geology. The dam foundation will be of highly jointed and sheared phyllitic rocks. The region also is seismically active. The design and construction problems examined are (1) the location of the dam axis; (2) the dam section; (3) the approach to static and dynamic stability analysis; and (4) the foundation treatment.

7.5-13 Nikolaev, I. I. and Fedorov, A. G., **Comparison of standard methods for calculating seismic loads on man-made structures** (Sravnenie norm opredeleniya seismicheskoi nagruzki, deistvuyushchei na iskusstvennye sooruzheniya, in Russian), *Stroitelstvo i arkhitektura Uzbekistana, 6,* 1975, 39–41.

Standard methods for calculating seismic loads employed in the U.S.S.R., U.S.A. and Japan are considered. The most common types of damage in tall bridges are listed on the basis of the effects of recent strong earthquakes in Japan and the U.S.A. The seismic loads on tall bridges calculated by Japanese and Soviet standards are in good agreement, while the standard U.S. calculation gives a value about one-half less.

● 7.5-14 Ng, S. F. and Kulkarni, G. G., **Optimum design of longitudinally stiffened simply supported orthotropic bridge decks,** *Journal of Sound and Vibration,* **40,** *2,* May 22, 1975, 273–284.

Design analysis of a stiffened bridge deck giving higher structural efficiencies in both static and dynamic behavior is particularly difficult because of the stochastic nature of vehicle parameters entering into the mathematical formulation of the problem. The present paper deals with the optimum solution based on the maximization of mass ratio and frequencies, resulting in minimum weight design sections having higher strength to weight ratios under static

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loads and smaller amplification factors under dynamic loads. Relationships between geometric dimensions of slab and stiffeners for two criteria of optimization are established by using the theory of orthotropic plate formulation and typical results are shown for practical ranges of design parameters. Comparative merits of the optimization criteria are discussed and conclusions are drawn based on applications to design problems.

7.5-15 Gadzhiev, A. B. and Sumchenko, E. I., **Effects of seismic excitation on joint seals of hydraulic structures** (Vliyanie seismicheskikh vozdeistvii na konstruktsiyu uplotnenii shvov gidrotekhicheskikh sooruzhenii, in Russian), *Gidrotekhnicheskoe stroitelstvo, 1*, 1975, 21–25.

Effects of earthquakes on various types of joint seals in dams are considered. A new seal design is presented. The design of the sliding joints of the tunnel under the San Francisco Bay is discussed. The requirements for such a design are described. Based on an analysis of the earthquake response of the dam, the requirements relating to the location of deformable joints are discussed. Constructive measures aimed at increasing the reliability of joints in dams in regions subject to earthquakes are suggested.

● 7.5-16 Lord, J. and Zayed, M., **Three dimensional elastic dynamic analysis of a 985 foot high freestanding communications tower**, *Bulletin of the New Zealand National Society for Earthquake Engineering*, 8, 3, Sept. 1975, 222–237.

This paper reviews the design development of a 985 ft-high free-standing communications tower recently constructed in San Francisco. Included is a description of the structural configuration of the tower and the criteria by which it was designed. The dynamic characteristics of a three-dimensional linear elastic mathematical computer model, devised to represent the physical structure, are presented. The dynamic responses of this computer model to various levels of ground shaking, including both horizontal and vertical excitations, are summarized, evaluated and compared to the seismic force levels prescribed by the 1969 edition of the San Francisco Building Code. Also included in the comparison are the responses derived for the tower from wind tunnel studies and static wind design criteria.

7.5-17 Golze, A. R., **Planning the Tehachapi Crossing**, *Journal of the Hydraulics Division, ASCE*, **101**, *HY1*, Proc. Paper 11052, Jan. 1975, 1-16.

Planning the California Aqueduct crossing of the Tehachapi Mountains in California north of Los Angeles involved 10 years of intensive research and study in the United States and Europe to design a 4,100-cfs (116,112 l/s), 2,000-ft (610 m) high-head pump lift, the largest in the United States. Engineering examination of alternate aqueduct routes over the high mountain ranges ended in selection of a crossing at El. 3100 (945.5 m). A study of the number of pump lifts was resolved in favor of a single lift on the ridge route. Model tests of various types of European and American pump designs identified as most suitable a vertical four-stage single-flow centrifugal pump 33 ft (10.065 m) in height, 16 ft (4.88 m) in diameter. Ten miles of 23.5-ft (7.18 m) diameter tunnel convey the pumped water through the mountain range. The Tehachapi Crossing has been in operation since October 1971.

● 7.5-18 McClelland, B., **Design of deep penetration piles for ocean structures**, *Journal of the Geotechnical Engineering Division, ASCE*, **100**, *GT7*, Proc. Paper 10665, July 1974, 705–747.

Ocean structures for oil development have been constructed, or planned for construction, on continental shelves off 60 countries and in water as deep as 840 ft. Descriptions of four significant structures in the Gulf of Mexico, Cook Inlet, North Sea, and Persian Gulf illustrate design and construction features of pile foundation systems currently used offshore in areas of severe environmental conditions. Pile size selection is dominated by substructure design considerations. Pile lengths to develop required axial capacities are estimated from static analyses using boring and test data. Designing pile wall thickness requires difference equation analyses to predict bending stresses resulting from wave and other lateral forces. Estimates of vertical and horizontal pile movements, as required to assist substructure design, also are obtained using difference equation solutions. Pile installation is primarily achieved by driving, using hammers with rated energies up to 600,000 ft-kips. Research needs to support the rapidly advancing development of ocean structures are examined.

● 7.5-19 Lee, K. L. and Focht, Jr., J. A., **Liquefaction potential at Ekotisk Tank in North Sea**, *Journal of the Geotechnical Engineering Division, ASCE*, **101**, *GT1*, Proc. Paper 11054, Jan. 1975, 1–18.

Design of a 93-m diameter x 90-m tall oil storage tank and production platform for the Norwegian North Sea required an investigation of the stability of the dense sand foundation against liquefaction from the wave-induced cyclic loads on the structure. The results of special cyclic loading triaxial tests, interpreted in terms of the expected maximum storm conditions, demonstrated the adequacy of the foundation and illustrated a number of new aspects concerning the liquefaction potential of sand under cyclic loading.

● 7.5-20 Richardson, G. N. and Lee, K. L., **Seismic design of reinforced earth walls**, *Journal of the Geotechnical Engineering Division, ASCE*, **101**, *GT2*, Proc. Paper 11143, Feb. 1975, 167–188.

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Seismic design for reinforced earth retaining walls was developed largely on the basis of results obtained from small laboratory scale walls on a shaking table. For this reason, the design is tentative and must await verification from further analytical laboratory and field studies. The laboratory tests showed that the walls responded like a nonlinear damped elastic system to the input vibrations. From measurements of the peak tie forces, an empirical design force envelope was developed which is a function of input acceleration only. It is suggested that the design earth pressures for an actual wall subjected to earthquake loading be based on this design force envelope, using a base acceleration determined by response spectra and modal participation factor techniques. Data also are presented of soil-tie friction under static and vibratory loading. The recommendations include data from which the required size and spacing of ties can be determined. Suggested factors of safety are given for tie pull out and tie breaking modes of failure.

7.5-21 Campbell, T. I., Francis, L. N. and Richardson, B. S., **A long curved post-tensioned concrete bridge without expansion joints,** *Canadian Journal of Civil Engineering,* 2, *3,* Sept. 1975, 262-269.

A long horizontally curved, post-tensioned concrete highway bridge, continuous over 12 spans, is described. Particular emphasis is placed on a number of original and unorthodox design concepts which make the structure unique.

● 7.5-22 Kartsivadze, G. N., **Earthquake resistance of highway structures** (Seismostoikost dorozhnykh iskusstvennykh sooruzhenii, in Russian), TRANSPORT Publishers, Moscow, 1974, 264.

Earthquake resistance of highway structures is discussed. Problems in the design and earthquake response of bridges, tunnels, pipes and retaining walls are considered.

General information about earthquakes is given and data on structural damage caused by strong-motion earthquakes are presented. Results of theoretical and experimental investigations of earthquake-resistant structural design are discussed. Special attention is paid to the practical problems of evaluating the behavior of highway structures subjected to seismic excitation. The foundations of calculating seismic loads are discussed. Numerical examples analyzing the response of bridges to seismic excitation are given.

The volume is intended for designers and construction engineers working in the area of earthquake-resistant transportation engineering, and it may be useful to researchers and university students.

● 7.5-23 Saini, S. S. and Kulkarni, V. H., **Behaviour of concrete gravity dams subjected to earthquakes,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 55-64.

For the earthquake-resistant design of a concrete gravity dam, a designer is interested in knowing the maximum probable earthquake expected for that site. Several methods are available for the dynamic analysis of dams, e.g. a one-dimensional beam analysis and a two-dimensional finite element analysis. However, these methods require the use of digital computers. Since such facilities are not readily available in many design offices, a field designer feels handicapped in carrying out the earthquake-resistant design of dams.

In order to evolve a simplified procedure, several dams with varying heights and cross-sectional shapes were analyzed for recorded earthquake excitations. The effect of various parameters on the dynamic behavior of gravity dams was investigated. Based on this study, average design curves are proposed for estimating the response of dams during earthquakes. This procedure is simple and quick and does not require knowledge of complicated methods of dynamic analysis. The procedure is, therefore, recommended for the preliminary design of dams located in seismically active areas.

● 7.5-24 Bhave, M. V., **Seismic design of earth dams,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 87-92.

As a result of the author's research at the Imperial College, London, a relation between the static factor of safety and the critical yield acceleration of an earth dam was established. Using this relation and adopting Ambrasey's empirical formula, the author calculates typical displacements for earth dams using factors of safety of 1.1, 1.25, 1.5 and 1.75 for typical seismic design coefficients of 0.05, 0.10 and 0.15. A criterion is suggested for an acceptable value of displacement of an earth dam.

● 7.5-25 Rao, P. V., **Earthquake risk as a design criterion in water resources projects,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 93-96.

Earthquakes, like storms, floods and hurricanes, are natural hazards. Since there is always some probability associated with the occurrence of earthquakes during the lifetime of a structure, it may be sufficient to ensure a reasonable level of design safety. A new concept of allowing limited risk in order to optimize the overall cost to the public of a project or structure has been gaining importance recently. Examples can be found in the remodelling of spillways against bigger floods, the designing of coastal structures against hurricanes and the incorporating of the

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balanced-risk concept in the new earthquake building codes of Long Beach, California. In this paper, these approaches are reviewed briefly, and a probabilistic model is described for computing the level of earthquake risk of water resource projects.

● **7.5-26** Chandorkar, A. V., **Design seismic coefficient and costs of gravity dams,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 65-68.

Different seismic design coefficients have been suggested by Indian authorities for the various regions of Maharashtra State. The purpose of this paper is to examine what effects seismic coefficient changes have on the design of a representative nonoverflow section of a gravity dam. Highlighted is how a small change in seismic design coefficients affects project economics. For this reason, careful selection of a seismic design coefficient is suggested.

● **7.5-27** Chopra, A. K. and Liaw, C.-Y., **Earthquake resistant design of intake-outlet towers,** *Journal of the Structural Division, ASCE,* **101,** *ST7,* Proc. Paper 11422, July 1975, 1349-1366.

The problem of designing reinforced concrete intake-outlet towers, partially submerged in water, to withstand earthquake ground motion is examined in general terms. It is shown that water surrounding the towers as well as the water inside them significantly affects the response to ground motion and that these hydrodynamic effects should be considered in the design of towers. A rational method for elastic design including the hydrodynamic effects is proposed. It is recommended that towers be designed to elastically resist ground motions which they may experience several times during their useful life. The ductility requirements that would be imposed on code-designed towers by the intense ground motions expected near the causative fault during high-magnitude earthquakes are evaluated; they appear to be rather large. It is recommended that forces for elastic design be increased so that the lateral displacement ductility requirements imposed by the most intense ground motion that can occur at the site would be no larger than a ductility factor of two.

● **7.5-28** Yudhbir and Varadarajan, A., **Influence of shear zones on the mechanism of stability of the foundations of Beas Dam, India,** *Engineering Geology,* 9, *1,* Mar. 1975, 53-62.

A case study is presented of an earth dam under construction in the Siwalik sedimentary rocks in northern India. The dam site is located in a seismically active zone. The shear zones incorporated in the rocks during folding control the stability of the dam foundations. Because the shear zones crop out in the river bed at different locations along the dam axis, the dam foundation is comprised of discrete blocks of varying resistance. The mechanism of stability is greatly influenced by the disposition of shear zones, and the relevant analysis is three dimensional.

● **7.5-29** Arya, A. S. and Kumar, K., **Earthquake resistant design of spillway bridge of Kolkewadi Dam,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 111-118.

A detailed dynamic analysis is made of the Kolkewadi Dam spillway and the bridge structure, with the spillway and the bridge structure being treated as an integral system. The bridge piers have been reinforced to provide ductility, and they have been designed to adequately withstand the dynamic effects in both the longitudinal and the transverse directions to the dam axis. In the longitudinal direction, the piers are found to be critical. Necessary seismic design considerations for the bridge span also are given, and special details at the bearings are recommended to check spalling of concrete and sliding and overturning of the bridge as a whole.

● **7.5-30** Chandrasekaran, A. R., Petrovski, J. and Bickovski, V., **Behaviour of a buttress dam,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 69-76.

The static and the dynamic behavior of a buttress dam are described. Different earthquake-type loadings are considered. The bottom regions of the upstream part of the dam have large tensile stresses necessitating reinforcement. For economic design, tensile stresses should be permitted, and the order of stresses may be related to the type of earthquake loading.

● **7.5-31** Syrmakezis, C. A., **Earthquake resistant design of electrical high voltage transmission lines,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 17-24.

The paper deals with the earthquake-resistant design of high voltage transmission lines and especially the earthquake-resistant design of the steel towers. The static loading of a tower and the calculation of its stiffness coefficients are discussed. The idealization of the space-truss tower into a seven-mass lumped system, the influence of the conductors, and the effect of soil-structure interaction on the seismic response of the tower also are considered. Since it is not possible to have a probable ground accelerogram for each tower site, a model for the estimation of ground motion is considered. The model is used for estimation of the ground movement under actual soil conditions. The soil condition effects are introduced subsequently in the governing differential equations for the calculation of the displacements and stresses of the tower. It is hoped that greater confidence in tower design will be achieved with the proposed method.

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● 7.5-32 Saran, S. and Prakash, S., **A new method of stability analysis of retaining walls in seismic areas,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 207-212.

Conventional stability analysis of a retaining wall involves examining it for overturning, sliding and bearing capacity. In this paper, a new method is proposed that combines all three requirements into one. Design charts are included for a few practical cases. The charts permit the base width of the wall to be determined if the height of the wall, the properties of the backfill and the design seismic coefficient are known.

● 7.5-33 Sridharan, A. and Raman, J., **Design of machine foundation using the reduced natural frequency-area relationship,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 227-230.

In the design of any machine foundation the resonance condition should be avoided because of its undesirable effects. Tschebotarioff in 1953, based on the performance records of many machine foundations, gave a method for designing them by relating the reduced natural frequency with the area of the foundation having a zone characterized as the "danger belt" for different types of soils. An analysis of the theories of the elastic halfspace and the mass spring dashpot model has been made, and it is shown that the reduced natural frequency varies inversely as the fourth root of the area. Tschebotarioff's plot also gives the same variation. To further confirm the relationship given in Tschebotarioff's plot, vibration experiments have been carried out on footings of various sizes on the natural ground surface. Vibration records published in the literature also have been used. All the test results, though obtained from different soils and test conditions, fall within the danger zone in the plot, clearly showing that resonance can be avoided as long as the reduced natural frequency does not fall within this zone.

● 7.5-34 Gupta, M. K. *et al.*, **Design of foundation for gas compressor,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 231-236.

The problem of machine foundation design for a gas compression plant is described. The plant was procured from France by the Dehradun Oil and Natural Gas Commission for installation at Oil Fields Ankleshwar. The foundation design used by the suppliers is evaluated and found to be inadequate for the site, which consists of yellow soil overlain by a layer of soft clay, with the water table remaining close to the surface. Alternative proposals of foundation design are examined from the viewpoint of vibrations, and these proposals are criticized. A typical undertuned foundation design is recommended.

● 7.5-35 Arya, A. S. and Thakkar, S. K., **Simplified dynamic design of arches for earthquake motions,** *The Journal of the Institution of Engineers (India),* 55, *CI 5/6,* May 1975, 179-185.

IS: 1893-1970—Indian Standard Criteria on Earthquake Resistant Design of Structures specifies a static uniform seismic coefficient approach for designing arches for earthquake loads. This paper compares the results of this analysis with the more rational elastic analysis based on dynamic principles using recorded accelerograms. It is seen that the code approach leads to unconservative distribution of internal forces in arches. Since the rational dynamic analysis is rather cumbersome for design office practice, a simplified semidynamic approach, which could be adopted for all practical designs, is evolved, using the extensive data calculated by the authors. It is possible that this approach may give results close to those which would be obtained by using the timewise mode superposition method.

● 7.5-36 Skinner, R. I., Kelly, J. M. and Heine, A. J., **Hysteretic dampers for earthquake-resistant structures,** *International Journal of Earthquake Engineering and Structural Dynamics,* 3, *3,* Jan.-Mar. 1975, 287-296.

The earthquake resistance of many structures can be increased by the inclusion of special components which act as hysteretic dampers. During moderately severe earthquakes these dampers act as stiff members which reduce structural deformations, while during very severe earthquakes the dampers act as energy absorbers which limit the quasiresonant buildup of structural deformations and forces. The hysteretic dampers are not required to withstand the main structural loads, and may therefore be optimized for their required stiffness and energy-absorbing features. On the other hand, the main structural components no longer require large energy-absorbing capacities and they may therefore be optimized for their required stiffnesses and load-bearing features.

For many structures this separation of component functions should lead to increased reliability at a lower initial cost. Under earthquake attack structural damage should be reduced. Nonstructural damage should be lower during moderately severe earthquakes, and for certain types of structures it should also be lower for very severe earthquakes.

Various ways in which hysteretic dampers may be utilized in structures are discussed briefly. The development of several types of high-capacity, low-cost hysteretic dampers, suitable for use in structures, is described. The dampers utilize solid steel beams, deformed plastically in various combinations of torsional, flexural and shear deformations.

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● 7.5-37 Skinner, R. I., Beck, J. L. and Bycroft, G. N., **A practical system for isolating structures from earthquake attack,** *International Journal of Earthquake Engineering and Structural Dynamics*, 3, 3, Jan.-Mar. 1975, 297-309.

The recent development of a range of hysteretic energy absorbers permits practical shock isolation systems to be incorporated in the bases of a wide range of structures. This isolation gives reduced earthquake loads which may be resisted by the normal lateral strength of the structure. Hence, a plastic reserve of earthquake resistance is no longer essential. A wider choice of architectural and structural forms is available with such an isolation system. The structures may be designed to prevent structural and nonstructural damage with a high degree of reliability. The special hysteretic dampers limit the lateral movement of the base of a structure to a few inches. With these small movements the lateral flexibility required for an isolating system can be conveniently provided for many structures by rubber bearings.

● 7.5-38 Gerwick, Jr., B. C., **Application of concrete drilling and production caissons to seismic areas,** *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2408, May 1975, 721-730.

The effects of strong seismic action on offshore concrete platform structures are severe accelerations and displacements, tsunamis, acoustic shock waves, and surface waves. The effective mass of the structure must include the hydrodynamic added mass. Seismic action may cause the soil to liquefy or slump, or may initiate turbidity flows or mud slides.

The horizontal accelerations of the structure develop heavy shears and moments. For the tower shafts of a typical structure, these are of the same order of magnitude as those developed by the design storm wave. However, the lateral shears and moments at the base of the structure may be two to four times those from the storm. The major factors are the size of the base and the rigidity of the structure-soil system. Added mass and damping coefficients are important factors, but for the typical structure, their influence is only moderate.

To minimize these forces, the structure must be designed to reduce the mass and added mass of the base. Controlled decoupling of the structure from the foundation appears to be a safe and practicable concept by which the structure can safely survive the maximum earthquake.

Soil stability under strong seismic action must be assured, using such means as penetration, drainage, and consolidation. Relative displacements of conductors and risers must be accommodated.

It is considered feasible and practicable to design and construct a concrete offshore platform to safely meet seismic criteria, including that from a very large earthquake.

● 7.5-39 Idriss, I. M., Dobry, R. and Power, M. S., **Soil response considerations in seismic design of offshore platforms,** *Proceedings, 1975 Offshore Technology Conference*, Offshore Technology Conference, Dallas, Vol. III, Paper No. OTC 2355, May 1975, 191-205.

Soil response aspects, related to the seismic design of offshore platforms, are summarized and discussed. Among these aspects, special attention is given to ground shaking and to soil failure potential. Analytical methods that may be used in evaluating soil response and in establishing seismic design parameters are described.

● 7.5-40 Hamada, M., Izumi, H. and Omori, K., **Behavior of underground tanks during earthquakes,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 41, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

Recently, many underground tanks for crude oil and liquefied natural gas, etc., have been constructed or planned in Japan, and most of these underground tanks are constructed on soft reclaimed land. In order to obtain the dynamic characteristics of underground tanks, earthquake observations, model tests and numerical analyses were carried out. A practical method for earthquake-resistant design of underground tanks is proposed on the basis of these results.

● 7.5-41 Velkov, M. and Jurukovski, D., **Reconstruction and comparative forced vibration studies of the stone arch bridge in Skopje,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 149, 4. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper represents the main results obtained during the repair of the old stone bridge in Skopje after the Vardar River regulation. Both the principles used in the repair and the technical solution were based on the assumption that the proven dynamic model of the bridge would not change after the repair was accomplished. From the results presented, the reader can judge whether the repair principles used can be applied in the repair or reconstruction of other cultural-historic monuments.

● 7.5-42 Kuribayashi, E., Iwasaki, T. and Kawashima, K., **Dynamic behavior of a subsurface tubular structure,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 49, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper, a new aseismic design criterion, seismic deformation analysis, is proposed for the construction of submerged tunnels. The criterion is based on wave propagation principles, avoiding the force method principles of the seismic coefficient method of design.

Subsurface ground conditions, such as density, elastic moduli and thickness, provide the natural period of the subground. Response displacements of the subsurface ground at specific sites are obtained by giving input accelerations to base rock and damping characteristics. Deformations and working stresses of the structural systems of the tunnel assumed to be an embedded beam or rod supported elastically by the ground are evaluated by sweeping values of the wavelength such as providing maximum stresses at a respective point of the tunnel structure.

● 7.5-43 Yanev, P. I. and Gonen, B., **Protection of essential mechanical equipment in seismic areas**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 126, 6. (For a full bibliographic citation see Abstract No. 1.2-8.)

Much earthquake-induced damage to essential equipment inside buildings is due to inadequate or nonexistent anchorages and restraints. This paper categorizes such damage, presents examples of specific design changes that would prevent this damage, and describes the anchorage requirements of several United States building codes. A case study demonstrates the low relative cost of upgrading anchorages in existing buildings to protect essential equipment.

● 7.5-44 Derham, C. J., Learoyd, S. B. B. and Wootton, L. R., **Building on springs to resist earthquakes**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 127, 5. (For a full bibliographic citation see Abstract No. 1.2-8.)

The cost of protecting a building from earthquake damage could be lessened if the accelerations it receives from the ground could be reduced. One way of doing this is to mount the building on elastic springs. This paper investigates the presence of springs, their stiffness and damping on a test building, modelled in a computer. The paper also compares the suitability of different spring materials for both the long term static and dynamic viewpoint and describes the large rubber mountings recommended.

7.5-45 Bakhtin, B. M. and Chernyavskii, V. L., **Effects of various design features on earthquake response of arch dams** (Vliyanie nekotorykh konstruktivniykh meropriyatii na robotu arochnykh plotin pri seismicheskikh vozdeistviyakh, in Russian), *Trudy koordinatsionnogo soveshchaniya po gidrotekhniki*, *87*, 1973, 81-83.

The effects of the nonmonolithic design of arch dams and the presence of aseismic belts on dynamic response of structures are studied using the example of the Toktogul Hydroelectric Power Plant.

● 7.5-46 Rashidov, T., **Dynamic theory of earthquake resistance of complex underground structures** (Dinamicheskaya teoriya seismostoikosti slozhnykh sistem podzemnykh sooruzhenii, in Russian), FAN Publishers, Tashkent, 1973, 179.

The purpose of this monograph is to present the principles of the dynamic theory of earthquake resistance of complex underground structures. In analogy with dynamic studies of aircraft, the underground structure is considered as a system of bars and massive rigid bodies interacting with the ground and having six degrees-of-freedom. The rheological principles governing the interaction between the ground and the structure are established experimentally. The intensity of seismic waves is assumed to vary in space and time and have an arbitrary direction with respect to the structure.

7.5-47 Natarius, Ya. I. and Ivanischev, V. F., **Design of earth dams for seismic loads** (Raschety plotin iz gruntovykh materialov na seismicheskoe vozdeistvie, in Russian), *Trudy Gidroproekta*, *32*, 1973, 51-62.

The dynamic response of dams and base yield is studied and a design method conforming to the codes coming into effect in Oct. 1972 is given. The engineering interpretation of dam response data corresponding to various earthquake parameters is analyzed.

7.5-48 Berezinskii, S. A. *et al.*, **Problems in structural design of dams in narrow canyons** (Nekotorye osobennosti raschetov ustoichivosti massivnykh plotin v uzkikh kanonakh, in Russian), *Trudy Gidroproekta*, *33*, 1974, 41-51.

Problems in structural design of large structures in a narrow canyon are considered and illustrated in the case of the Toktogul Hydroelectric Power Plant. The topographic and geological conditions at the site are complex, and the level of seismic activity is high. Structural design of the dam must take into account the natural bend of the Naryn River as well as tectonic faults in the base of the dam. It is shown that by including the shearing strength of rock masses and taking account of the system of crack formation in them the volume of concrete dams in narrow canyons can be substantially reduced.

7.5-49 Tsiskreli, Ts. G., **Displacements of circular arcs of constant cross section for earthquake-resistant arch dam design using the conjugate arc method** (Peremeshcheniya krugovykh arok postoyannogo secheniya dlya rascheta arochnoi polotini na seismostoikost po sposobu vzaimnoso-

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pryazhennykh arok, in Russian), *Seismostoikost sooruzhenii, 3*, 1974, 118–123.

An arch dam design method is outlined which uses as an approximation a system of horizontal arcs with rigid ties between them. The interaction between the arcs is taken into account. Special attention is paid to stresses parallel and normal to the reservoir axis together with bending moments and normal and transverse forces. The response of circular arcs with the rigidly fixed abutment is computed using bending moments and longitudinal and transverse forces. Conditional deflections at various cross sections of the arc are presented.

● **7.5-50** Baron, F. and Hamati, R. E., **Seismic studies of the articulation for the Dumbarton Bridge replacement structure, Vol. 1 - Description, theory, and analytical modeling of bridge and components,** *EERC* 75-8, Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1975, 143. (NTIS Accession No. PB 251 539)

In this volume and in Volume 2 (see Abstract No. 7.5-51), the influences of various girder types and joint articulations on the seismic responses of long multispan highway bridges are reported. The girder types are of cast-in-place and precast concrete construction and steel twin-box sections. Various types of expansion joints and girder to pier-cap connections are considered. A 7400 ft long bridge which will cross the lower arm of San Francisco Bay is studied. The bridge is composed of 43 spans founded on various soil conditions, including thick mud and deep water sections.

This volume includes a description of two alternate designs for the Dumbarton Bridge structure and the selection of the final design for the structure over the thick mud sections. Also presented are the theory and analytical techniques used to model the bridge and components.

● **7.5-51** Baron, F. and Hamati, R. E., **Seismic studies of the articulation for the Dumbarton Bridge replacement structure, Vol. 2 - Numerical studies of steel and concrete girder alternates,** *EERC* 75-9, Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1975, 141. (NTIS Accession No. PB 251 540)

This volume continues from Volume 1 (see Abstract No. 7.5-50) the report on the influences of various girder types and joint articulations on the seismic responses of long multispan highway bridges.

Response characteristics are determined for light, moderate and severe ground motions of both the thick mud and deep water sections on which the Dumbarton Bridge replacement structure is founded. Time history and spectral analyses based on design and response spectra are performed for two- and three-dimensional models. Interactions of water mass, soils, footings and piling groups are considered.

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8. Earthquake Effects

8.1 General

8.1-1 Page, R. A., Blume, J. A. and Joyner, W. B., **Earthquake shaking and damage to buildings,** *Science,* **189,** *4203,* Aug. 22, 1975, 601-608.

This article is a general discussion of the nature of strong ground shaking from earthquakes and of methods for estimating the effects of shaking on buildings. Much of the discussion focuses on the San Francisco Bay region—one of the most seismically hazardous areas in the United States. The authors consider what the effects of a repetition of the 1906 San Francisco earthquake would be on present-day structures in the San Francisco Bay area. They conclude that, although most buildings are probably more resistant than is indicated by conventional analytical procedures, many may not be able to withstand the intense shaking that can occur close to the causative fault. A repetition of the 1906 San Francisco earthquake today could cause tens of thousands of deaths and billions of dollars of damage. Such potential losses could be reduced through improved engineering and construction practices and through more judicious land utilization.

● 8.1-2 Blume, J. A. *et al.,* **Earthquake damage prediction: A technological assessment,** *17,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Oct. 1975, 79.

In general, there are two approaches for predicting damage characteristics of a site. Either a statistical study of recorded damage data for past earthquakes can be conducted, or a theoretical model of anticipated structural behavior can be constructed. This study presents a method based on each approach as well as a method combining features of both. The results of a comparative analysis of the variation in damage estimates given by the three damage prediction techniques are summarized.

● 8.1-3 Taleb-Agha, G., **Seismic risk analysis of networks,** *MIT-CE R75-43,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Nov. 1975, 135.

The purpose of this report is to show how seismic risk analysis of networks with continuous links can be performed efficiently without loss of accuracy. An efficient scheme for the topological transformation of networks is presented. For networks with deterministic link resistances, a minimax approach has been developed to calculate the probability of the network failing to meet a given set of requirements due to threats coming from a given set of seismically active source areas and/or faults with known seismic history. In this approach, which proved to be very effective, the network is dynamically modeled by an equivalent network with discrete sites. The report also shows how networks with random link resistances can be analyzed effectively with the notion that such networks with larger sizes must either be analyzed by decomposition (if possible) or by considering the links to have deterministic resistances. An efficient computer program based on the minimax approach has been developed and tested on several pilot problems. In this report, the network of major highways surrounding the Boston, Massachusetts, area is analyzed, and the results are compared with those reported in the literature.

● 8.1-4 Taleb-Agha, G., **Seismic risk analysis of lifeline networks,** *MIT-CE R75-49,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Dec. 1975, 80.

The aim is to show how seismic risk analysis of lifeline networks can be performed efficiently without loss of accuracy. Two efficient schemes have been developed to find the probabilities of partial network failure due to threats coming from a given set of seismically active source areas and/or faults with known seismic history. Networks with deterministic link resistances and those with random

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link resistances can be analyzed. Both schemes start with the transformation of the given network and its objective to an equivalent SSP-network which is simpler to handle and has a certain number of tie-sets. Then the probability that any desired number of these tie-sets fail simultaneously in any given year is evaluated. An efficient computer program for the deterministic resistance approach has been developed and tested on several pilot problems. The network of major highways surrounding the Boston, Massachusetts, area is analyzed, and the results are presented herein.

8.2 Studies of Specific Earthquakes

● 8.2-1 Keightley, W. O., **Destructive earthquakes in Burdur and Bingol, Turkey - May 1971**, National Academy of Sciences, Washington, D.C., 1975, 82.

This report is intended to contribute to the supplying of technical knowledge and advice that can reduce the loss of life and property in the seismically active area of Turkey. In the first section of the report, there are short discussions of the seismic risk in Turkey, construction practices, prices of building materials and building regulations. The next section presents photographs and descriptions of the damage caused by the Burdur and Bingöl earthquakes of May 1971. The final section includes recommendations for structural improvements and for better dissemination and enforcement of building design and construction regulations in Turkey.

● 8.2-2 Meehan, J. F., **Reconnaissance report of the Veracruz, Mexico earthquake of August 28, 1973,** *Bulletin of the Seismological Society of America*, **64**, *6*, Dec. 1974, 2011-2025.

The purpose of the visit to the site of the 1973 Veracruz earthquake was to evaluate its effects with respect to the current California statutes and regulations, particularly those concerning public school and hospital construction, and to determine if the state of California should make further investigations of any aspect of the earthquake.

The ground motion was not as strong as expected from an earthquake of 6.8 magnitude, judging from the lack of damage to both structures and equipment. The 80- to 100-km focal depth had a very definite influence on the ground motion at the surface. Depths of California earthquakes usually range from 5 to 15 km. There was little indication of any vertical acceleration and the effective horizontal acceleration was rather low, as generally evidenced by the response of buildings and equipment.

By comparing the damage produced in similar construction, it is possible to obtain an interesting evaluation of the effects of earthquake depths. The high damage level to the construction reported for the shallow (about 5 km) Dec. 23, 1973, Managua, Nicaragua, earthquake, magnitude 6.2, should be compared to the low damage level shown for this deep (about 80 km) Veracruz earthquake.

As has been evidenced in this and all previous earthquakes, the need for engineering consideration of relative rigidities of structures, the resulting horizontal torsional forces and load distribution, the need for complete and logical structural systems, the need to provide adequate ties and struts within structural systems, the need to properly reinforce masonry, and the need to properly anchor architectural, mechanical and electrical finishes, fixtures and equipment are critical to aseismic design and construction. No evidence was found to substantiate any revisions in the current California regulations for school or hospital buildings.

● 8.2-3 Shteinberg, V. V., Ershov, I. A. and Darbinyan, O. S., **Ground motion and seismic effects in the strong earthquake of November 24, 1971, in Petropavlovsk-Kamchatskii** (Kolebaniya grunta i seismicheskii effekt v Petropavlovske-Kamchatskom pri silnom zemletryasenii 24 noyabrya 1971 g., in Russian), *Voprosy inzhenernoi seismologii*, *17*, 1975, 20-33.

Macroseismic and instrumental data obtained during the strong earthquake of Nov. 24, 1971, near Petropavlovsk-Kamchatskii are analyzed. Based on an investigation of building damage and the effects of the earthquake on various objects, a map of the town showing the distribution of seismic intensities is constructed.

Reaction spectra of the territory of the town for the strongest potential earthquake are analyzed. The results obtained are in complete agreement with the seismic microzoning map of the town constructed in 1964-65.

● 8.2-4 Borisova, N. S. *et al.*, **Macroseismic investigations of the effects of the November 24-25, 1971 earthquake in Petropavlovsk-Kamchatskii and a comparison with seismic microzoning** (Makroseismicheskoe obsledovanie posledstvii zemletryaseniya 24(25) noyabrya 1971 g. v Petropavlovske-Kamchatskom i sopostavlenie rezultatov s seismicheskim microraionirovaniem, in Russian), *Voprosy inzhenernoi seismologii*, *17*, 1975, 71-86.

Results of macroseismic investigations of the effects of the Nov. 24-25, 1971, earthquake in the town of Petropavlovsk-Kamchatskii (magnitude 7.2) are presented. The investigations included between 30% and 60% of the various types of buildings in the town. Earthquake intensities in the greater part of the town were between 6.5 and 7. Among the sites investigated, the minimum intensity found was 5 and the maximum 8. A comparison of the data obtained with intensities predicted by the seismic micro-

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zoning map of the town constructed by the Earth Physics Inst. of the U.S.S.R. Academy of Sciences in 1961–64 corroborates, on the whole, the conclusions of the microzoning project.

● 8.2-5 Tomblin, J. F. and Aspinall, W. P., **Reconnaissance report of the Antigua, West Indies, earthquake of October 8, 1974,** *Bulletin of the Seismological Society of America,* **65**, *6,* Dec. 1975, 1553–1573.

A major earthquake (m_b = 6.6; M_S = 7.5, U.S. Geological Survey) occurred in the northern Lesser Antilles on Oct. 8, 1974, causing damage of modified Mercalli intensity VIII on the island of Antigua and lower intensities on the more distant islands.

The damage was confined mainly to larger and older buildings, to a petroleum refinery, and to a deep-water harbor. No earthquake-resistant building code exists in most of the Lesser Antilles, and in the majority of cases examined, it was clear that structural damage had occurred because the building concerned could not have met the elementary requirements of a typical code. A few people received minor injuries, but no fatalities were reported.

The hypocenter of the main shock and many of the aftershocks lay about 30 km above the westward-dipping zone defined by activity over the last decade. The earthquake was tectonic in origin since the epicenter was 50 km from the nearest recent volcano.

● 8.2-6 Karaesmen, E., **A survey of the 1st February 1974 Izmir (Turkey) earthquake,** *Fifth Symposium on Earthquake Engineering,* Sarita Prakashan, Meerut, U.P., India, Vol. 1, Nov. 1974, 339–350.

The Izmir region is one of the most seismically active regions of Turkey. More than eighty earthquakes have occurred in this region during this century. Some of the earthquakes have been magnitude 6.0 and higher.

On Feb. 1, 1974, Izmir, the third largest city in Turkey, experienced a medium-sized earthquake. Although the earthquake was small in magnitude, its psychological and structural effects were pronounced since the earthquake occurred during the night.

Records were obtained from seismoscopes located in alluvial and volcanic zones. The north-south component of the ground motion was dominant. The measurements of relative displacement, velocity, and maximum spectral acceleration taken on alluvial soil were twice as high as the measurements taken on bedrock. The structural damage in the alluvial field zones was much greater than the damage in the volcanic rock zones. A statistical study of reinforced buildings located in the immediate vicinity of the seismoscopes showed that buildings near the coast were most severely affected by the earthquake. A structural analysis was made of a building that collapsed because of the failure of its ground floor columns. It is suggested that the effects of different types of soil on ground motion be introduced into the Turkish building code and that care be exercised in the design and construction of buildings, especially of those on alluvial deposits.

● 8.2-7 Moinfar, A. A., **Some engineering aspects of Managua earthquake of December 1972,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 140, 12. (For a full bibliographic citation see Abstract No. 1.2-8.)

On Dec. 23, 1972, an earthquake of magnitude 6.25 occurred in Managua; as a result of this earthquake the city was destroyed. The most seriously damaged area was the downtown area in which several important buildings were located. Some multistory modern buildings resisted the earthquake well, some were moderately damaged; and some were seriously damaged or totally collapsed. As a consequence of the earthquake, the economy and administration of the entire country were severely disrupted, and the government had to solve a multitude of new problems. The painful lessons learned in Managua are useful as a guide for policy and pre-planning activities in similar cities.

8.2-8 Horiuchi, S. *et al.*, **Field study on the Izu-Hanto-oki earthquake of 1974 (No. 1): On the hazards and the factors of outbreak of fires caused by this earthquake** (in Japanese), *Transactions of the Architectural Institute of Japan, 233,* July 1975, 109–119.

On May 9, 1974, the Izu-Hanto-oki earthquake caused extensive damage in the Japanese district of Minami-Izu cho. L.P. gas containers were overturned and gas pipelines were damaged. As a result of gas leakages, fires occurred. This paper presents the results of a survey of households located in the district. The purposes of the survey were to determine the intensity of ground motion, the number of gas leakages and the relationship between the outbreak of the fires and ground motion intensity and the leakages.

8.3 Effects on Buildings

● 8.3-1 Hudson, D. E. and Jephcott, D. K., **The San Fernando earthquake and public school safety,** *Bulletin of the Seismological Society of America,* **64**, *6,* Dec. 1974, 1653–1670.

The San Fernando earthquake was an unusually valuable test of school safety because: (1) there were several hundred schools having structures of all types in the heavily shaken area, including 10 schools within 5 miles of the epicenter; (2) the severity of ground motion is believed to have been near the maximum to be expected for an earthquake of any size—a number of campuses were subjected to major ground cracking and deformation; (3) since there were many instruments in the area, the details of the earthquake ground motion are better known than for any other earthquake. On some campuses, pre-Field Act buildings, renovated pre-Field Act buildings, and new buildings existed side by side, and direct comparisons show the efficacy of the Field Act and the associated plan check and field inspection procedures in reducing the earthquake hazard to an acceptably low level. No structural failures that would have been likely to cause serious injury or death if the buildings had been normally occupied at the time of the earthquake occurred in any buildings built to current standards. There were, however, some failures of nonstructural elements that could have resulted in hazardous situations; these failures demonstrate the need for upgrading requirements in the nonstructural area of building construction.

● 8.3-2 Scholl, R. E., **Low-rise building damage from low-amplitude ground motions,** *Bulletin of the Seismological Society of America*, **64**, *6*, Dec. 1974, 1743–1755.

Data on offsite low-rise building damage from underground nuclear testing at the U.S. Atomic Energy Commission's Nevada Test Site are available for seven large tests in the period from 1966 to 1970. The data, while sparse, provide an adequate sample for the investigation of motion-damage relationships. Damage in the study is described statistically in terms of the incidence of damage complaints, the incidence of buildings damaged and damage cost. Using 5 per cent-damped response-spectrum acceleration amplitude to characterize ground motion, the plotted data fit reasonably well with previous motion-damage relationships established from extensive data available from the 1969 RULISON underground nuclear explosion experiment conducted in western Colorado.

● 8.3-3 Celebi, M. and Gülkan, P., **The Akkum building during the February 1, 1974 Izmir earthquake and its repair,** *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 135, 9. (For a full bibliographic citation see Abstract No. 1.2-8.)

Brief comments are made on the causes of damage to the Akkum building. Emphasis will be placed on the erroneous construction practices of the repair personnel. Serious errors were made on the connections of longitudinal reinforcing bars during cap-repairing of columns and newly added shear walls.

8.3-4 Mochizuki, T., **An investigation of actual conditions of wooden houses in Tokyo and their earthquake response** (in Japanese), *Transactions of the Architectural Institute of Japan*, *230*, Apr. 1975, 73–83.

This paper describes an investigation of the condition and distribution of wooden houses in all districts of Tokyo. Described are their uses, number of stories, and the ratio of effective wall length to building area. The collapse process was studied, and vibrational damage was measured, using earthquake response analysis. Calculated damage ratios show good agreement with the actual damage caused by the 1923 Kanto earthquake to wooden houses in the downtown districts which are located on thick alluvium.

● 8.3-5 **Effects prediction guidelines for structures subjected to ground motion,** *JAB-99-115, UC-11*, URS/John A. Blume & Assoc., San Francisco, July 1975, 373.

To cover the broad range of effects prediction needed for a typical underground nuclear explosion (UNE) project, three distinct but interrelated methods have been developed and are described.

The fundamental practical and theoretical aspects of predicting the effects of dynamic ground motion on structures are summarized. Experimentally derived and theoretically determined observations of the behavior of typical structures subjected to ground motion are presented. Based on these fundamental considerations and on the observed behavior of structures, the formulation of the three effects prediction procedures is described, along with guidelines regarding their applicability. Example damage predictions for hypothetical UNEs demonstrate these procedures.

To aid in identifying the vibration properties of complex structures, one chapter discusses alternatives in vibration testing, instrumentation, and data analysis. Finally, operational guidelines regarding data acquisition procedures, safety criteria, and remedial measures involved in conducting structure effects evaluations are discussed.

● 8.3-6 Scholl, R. E., **Project RIO BLANCO, low-rise building damage study,** *JABE-NSF-01*, URS/John A. Blume & Assoc., San Francisco, Dec. 1975, 46.

Ground motion and damage data from selected towns surrounding the RIO BLANCO underground nuclear explosion gas stimulation experiment were collected for the purpose of investigating motion-damage relationships for low-rise buildings. The statistically determined motion-damage relationships are given in terms of incidence of complaints (complaint ratio), incidence of damage (damage ratio), and damage cost (damage factor).

The principal purpose for conducting the study was to determine the validity of previously determined motion-damage relationships in the threshold damage range of ground motion. Results of the study verify the previously determined complaint ratio and damage ratio statistics but indicate that damage factors determined from the RIO

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BLANCO study are slightly lower than those determined from previous underground nuclear explosions.

● 8.3-7 Wong, E. H., **Correlations between earthquake damage and strong ground motion,** *MIT-CE R75-23,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, June 1975, 87.

The primary data for this study come from approximately 40 buildings in Los Angeles from which both information as to damage ratio and strong motion records were obtained during the San Fernando earthquake in 1971. A few additional buildings, in Managua and near Los Angeles, are added. For these additional buildings, all of which were heavily damaged during earthquakes, the general level of earthquake shaking can be inferred with reasonable confidence. Damage ratio is correlated with spectral displacement, spectral velocity, spectral acceleration (these spectral quantities were averaged over periods from 10% less than the pre-earthquake fundamental period to 10% greater than the during-earthquake period) and with calculated interstory displacement. The most useful correlations related damage ratio to spectral velocity and spectral accelerations.

8.4 Effects on Miscellaneous Structures and Systems

● 8.4-1 Katayama, T., Kubo, K. and Sato, N., **Earthquake damage to water and gas distribution systems,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 396–405.

Some of the quantitative results obtained from past earthquake reports on the seismic damage to underground water and gas distribution pipelines are described. The average number of breaks per unit length of piping is summarized for pipelines of different materials. Some comments also are made on the effect of pipe diameter on damage. Damage ratios are discussed in relation to the intensity of ground shaking. Results of the quantitative analysis of the relation between seismic damage and ground condition are reported.

● 8.4-2 Seed, H. B. *et al.,* **The slides in the San Fernando dams during the earthquake of February 9, 1971,** *Journal of the Geotechnical Engineering Division,* ASCE, **101,** *GT7,* Proc. Paper 11449, July 1975, 651–688.

The Feb. 9, 1971, earthquake in San Fernando Valley, California, caused slides in the embankments of two old adjacent hydraulic fill dams. At the 140-ft high lower dam, the entire upstream face slid into the reservoir leaving only 5 ft of freeboard. At the 65-ft high upper dam, the entire embankment from the waterline to the downstream toe moved downstream 6 ft, leaving a scarp just below the reservoir level on the upstream face. It is concluded that the slide in the lower dam resulted from the development of an extensive zone of liquefaction near the base of the embankment. Some liquefaction also is believed to have occurred in the upper dam; however, since a significant body of the sand in the upstream and downstream shells of this dam retained considerable strength, complete failure could not occur and the movements were limited in extent. Conclusions are presented concerning the applicability of analytical procedures for predicting the failure and movements that occurred.

● 8.4-3 Hara, F., **A new method of earthquake damage analysis for industrial facilities and its application to the cases of recent earthquakes in Japan,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 133, 14. (For a full bibliographic citation see Abstract No. 1.2–8.)

This paper deals with a new method for analyzing earthquake damage to industrial facilities such as oil storage tanks, piping systems in chemical plants and so on. This new method is shown to be powerful for finding the relationship of failure potential between each structural element of an industrial system and to be applicable for estimating the degree of damage which would be caused by future earthquakes in industrial facilities. The author applies this method to the case of the damage to oil storage tanks in the 1964 Niigata earthquake and in the 1968 Tokachi-oki earthquake and also to the case of the damage to L.P.G. fuel bomb (small gas container) systems in the 1974 Izuhanto-oki earthquake.

8.5 Effects and Near Surface Geology

● 8.5-1 Babayan, T. O., **Macroseismic re-evaluation of the effects of the 1926 Leninakan earthquake** (Povtornoe makroseismicheskoe obsledovanie posledstvii zemletryaseniya 1926 goda na territorii g. Leninakana, in Russian), *Byulleten po inzhenernoi seismologii,* 9, 1975, 114–120.

Data from a macroseismic re-evaluation of the effects of the 1926 Leninakan earthquake are presented. The data are compared with the MSK-64 scale. As a result, intensities are calculated more precisely in relation to various types of structures and in relation to hydrogeological and soil conditions in Leninakan.

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9. Earthquakes as Natural Disasters

9.1 Disaster Preparedness and Relief

● 9.1-1 Sato, S., **Earthquake-proof system in civil engineering**, *Technocrat*, 7, 3, Mar. 1974, 70–80.

A general description of Tokyo's earthquake disaster prevention plan and some specifics of the projects being carried out in the Koto and Shirahige districts are presented. Particular emphasis is given to the planning, construction and safety of earthquake shelters.

● 9.1-2 **The earthquake threat in Quebec**, *Emergency Planning Digest*, 1, 3, Nov.-Dec. 1974, 2–9.

This study, prepared by Quebec Civil Protection (Protection Civile) and updated from previous studies, puts emphasis on the threat of earthquakes in that province. Circulated to provincial planners, the study is intended to provide local authorities with background information and emergency advice for distribution to the public.

● 9.1-3 Duke, C. M. and Moran, D. F., **Guidelines for evolution of lifeline earthquake engineering**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 367–376.

Recent achievements in the field of earthquake engineering as applied to public utility and transportation systems are presented. The goals and priorities for future progress in the field are discussed; a tentative set of action guidelines is outlined.

● 9.1-4 Whitman, R. V., Cornell, C. A. and Taleb-Agha, G., **Analysis of earthquake risk for lifeline systems**, *Proceedings of the U.S. National Conference on Earthquake Engineering-1975*, Earthquake Engineering Research Inst., Oakland, June 1975, 377–386.

The importance of asking what the probability is that various parts of transportation, water, power, communications and other vital systems might fail during a single earthquake is emphasized. The effect of the geographical dispersion of key facilities on the answer to this question is illustrated by simple examples.

9.1-5 Kawamura, T., **Theme quantification for the prevention plan of disaster: Application of grouping method by Markov chain** (in Japanese), *Transactions of the Architectural Institute of Japan*, 233, July 1975, 143-150.

A simulation method for quantifying disaster prevention plans is presented. Absorption Markov and ergodic Markov chains are used in a computerized analysis to group together the important functions which must be performed during all types of disasters. As the end result, the total system is organized into a hierarchy. Two indexes—an index of systematization and an index of dispersion—are used to check the efficiency of the system.

The author advocates the feasibility of using this method in the preparation of simulated plans which would be both low in cost and which would meet legal requirements.

9.2 Legal and Governmental Aspects

● 9.2-1 Kobayashi, H., **Seismic microzoning for urban planning**, *Technocrat*, 7, 8, Aug. 1974, 80–98.

In this paper, the theoretical background of seismic microzoning in Japan and the techniques used in the application of it are discussed. It is advocated that seismic

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

microzoning be taken into account in the planning of an urban area.

● 9.2-2 Steinbrugge, K. V. and Degenkolb, H. J., **Meeting the earthquake challenge: California's new laws,** *Civil Engineering, ASCE,* 45, 2, Feb. 1975, 44-47.

California's recent earthquake laws are breaking new ground in public policy matters. In turn, these changes in law are also having a significant impact on the approaches to civil and structural engineering designs for specific projects as well as for other aspects of engineering practice. For one example of the intent of the new laws, new hospitals must not only remain safe, but must remain functional after the event insofar as practicable. Secondly, although dams are to be constructed according to the state-of-the-art of earthquake-resistant design, they are not necessarily held to be perfectly safe since downstream inundation maps are required and thereby an acceptable level of risk is implied for downstream construction. Lastly, land use restrictions are having increasing influence with respect to new construction in geologically hazardous earthquake areas such as fault zones.

● 9.2-3 O'Connor, E. M., **Correcting existing earthquake hazardous buildings in the city of Long Beach, California,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 216-225.

An account of the changes promulgated in building regulations in Long Beach, California, from the time of the 1933 earthquake to the present is presented. Particular attention is given to a description of Subdivision 80 of the Long Beach building regulations and to the activities carried out under it. The seismic safety study prepared for the city also is discussed.

● 9.2-4 Iwan, W. D., **Earthquake resistance of public utility systems - A report on findings of the California Governor's Interagency Earthquake Committee,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 387-395.

As a result of a recommendation made by the California Governor's Earthquake Council, in 1973 the Subcommittee on Earthquake Resistance of Public Utility Systems was formed. The subcommittee consists of 33 representatives from public utilities, government agencies and earthquake research organizations.

The first report of the Subcommittee was submitted in June 1974. The report covered five main areas: (1) current earthquake resistance criteria in public utility design and construction, (2) present research on earthquake resistance in public utility design and construction, (3) recommendations for further research on earthquake resistance in public utility design and construction, (4) funding of research on earthquake resistance of public utility systems, and (5) general subcommittee recommendations. This paper summarizes the findings of the subcommittee in the first three areas.

● 9.2-5 Meehan, J. F., **California's seismic safety for hospitals,** *Proceedings of the U.S. National Conference on Earthquake Engineering-1975,* Earthquake Engineering Research Inst., Oakland, June 1975, 357-366.

A brief history is given of the background of the various conditions and events leading up to the adoption of statutes designed to maintain continuous functional operation of hospitals after earthquakes. Highlights of the statutes and the enforcement of them are also presented.

● 9.2-6 **A proposal for citizen's review community safety plan for the comprehensive plan of San Francisco,** San Francisco Dept. of City Planning, 1974, 69.

The publication is a proposal for citizen review of the proposed Community Safety Element of the Comprehensive Plan of San Francisco. The purpose of this element is to provide the basis for inclusion of geologic and fire hazard concerns in the city's planning and development process.

The proposal is organized into three major sections: Background, Objectives and Policies, and Programs. The Background section presents, in general terms, the subject of seismicity at both the global and more local levels. The major investigations conducted in preparing this proposal (geology, structures, emergency operations, reconstruction) are documented, and the findings and implications for planning are presented. The conclusion of this section discusses life safety concerns and the kinds of risks the community faces from seismic hazards as well as needs for abatement of identified hazards.

The second section, Objectives and Policies, is organized into four major areas of concern: (1) Life safety, (2) Preservation, (3) Emergency operations, and (4) Reconstruction. It is this second section that will, after public review, be revised and proposed to the City Planning Commission for adoption as part of the Comprehensive Plan of San Francisco.

The third and final section is Programs. This section outlines short- and long-range actions that can be taken to implement the objectives and policies of the preceding section.

● 9.2-7 **San Francisco seismic safety investigation,** URS/John A. Blume & Assoc., San Francisco, June 1974, 124.

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

This report summarizes the work of two seismic studies of the city of San Francisco. The studies consisted of a geologic evaluation and a structural evaluation of earthquake hazards within the city. Principal output from these studies consists of the identification of the major geologic and structural hazards that are summarized in a series of maps delineating where in the city these hazards are believed to exist. Results of this study will aid in minimizing future loss of life and economic loss due to earthquakes through disaster-mitigation procedures and future land-use planning.

● 9.2-8 Eiby, G. A., **A history of anti-seismic measures in New Zealand,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 8, *4,* Dec. 1975, 255–259.

The existence of a seismic problem in New Zealand was recognized in 1848. Limited governmental action and pioneering structural investigations followed. There were no major disasters between 1855 and 1929, and interest in earthquakes declined. Nevertheless, several papers by New Zealanders were published in the early 1920's, and the schools of engineering and architecture drew the attention of students to seismic problems. Modern building regulations have their origin in the report of a committee set up after the Hawke's Bay earthquake in 1931, but some local authorities have still to adopt antiseismic measures. The Hawke's Bay earthquake also stimulated observational seismology. The earliest civil defense legislation was intended to deal with riots, and later with the effects of air attack. The organization has only recently become concerned with natural disasters. Relief measures were traditionally, and still are, considered a matter for local bodies or for the police and armed forces. Unique insurance measures were introduced during the Second World War. Since then there has been continuous advance in engineering and seismological research, improvements in building regulations, insurance provisions, and the organization of civil defense.

9.3 Socio-Economic Aspects

9.3-1 Horiuchi, S. *et al.*, **Field study of the Izu-Hanto-oki earthquake of 1974 (No. 2): Study on human behaviour in the earthquake** (in Japanese), *Transactions of the Architectural Institute of Japan, 234,* Aug. 1975, 51–60.

The Izu-Hanto-oki earthquake, which occurred in Japan on May 9, 1974, caused a great deal of damage in the district of Minami-Izu cho. Interviews were conducted at each household in the district to determine the reaction of the people during the earthquake and afterward. The survey results are described.

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